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**SIMULTANEOUS CHATANIKA RADAR AND S3-2 SATELLITE
MEASUREMENTS OF IONOSPHERIC ELECTRODYNAMICS IN
THE DIFFUSE AURORA**

Richard R. Vondrak

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Menlo Park, California 94025

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Simultaneous Chatanika radar and S3-2 satellite measurements have been used to investigate the spatial variation of the electrical properties of the auroral-zone ionosphere. Of special interest are the latitudinal variations of the ionospheric electric field, ionization, conductivity, and currents. This report compares the simultaneous radar and satellite measurements during two early-evening passes in February 1976. Measurements by the radar and satellite were remarkably consistent, except for the ionization and temperature measurements by the S3-2 Langmuir probe. During both passes, the equatorward			

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*boundary of the diffuse aurora was nearly overhead at Chatanika, Alaska. Although the configurations of ionization and conductivity were nearly identical in these two passes, the latitudinal variations of the ionospheric electric field and field-aligned current were quite dissimilar. In one pass (Revolution 1031 on 17 February 1976), the auroral electric field extended into the trough, penetrating to about 20° equatorward of the diffuse aurora. In the other pass (Revolution 1144 on 25 February 1976), the electric field and field-aligned current were negligibly small in the trough, but were substantially enhanced at the diffuse auroral boundary. Because the ionospheric morphology was so similar on the two days, the source of the different electrodynamic patterns appears to be related to magnetospheric conditions. This report also identifies simultaneous data sets from early 1978, including examples of the radar measurements.

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CONTENTS

LIST OF ILLUSTRATIONS	iv
LIST OF TABLES	vi
ACKNOWLEDGEMENTS	vii
I INTRODUCTION	1
II MEASUREMENTS OF PREMIDNIGHT DIFFUSE AURORA	3
A. Measurements During Revolution 1031 on 17 February 1976	3
1. Chatanika Radar Measurements	3
2. S3-2 Plasma-Density and Temperature Measurements	10
3. S3-2 Electric-Field Measurements	15
4. S3-2 Magnetic-Field Measurements	17
5. S3-2 Energetic Electron Measurements	19
B. Measurements During Revolution 1144 on 25 February 1976	23
1. Chatanika Radar Measurements	23
2. S3-2 Satellite Measurements	29
C. Interpretation of the Measurements	32
III COORDINATED EXPERIMENTS DURING 1978	43
IV CONCLUDING REMARKS	49
REFERENCES	50

ILLUSTRATIONS

1	S3-2 ground track during Revolution 1031 on 17 February 1976. The heavy solid line denotes the latitudinal extent of E-region measurements at the 100 km altitude. The pointing directions while the radar is in the fixed-position mode are also indicated	4
2	Spatial variation of ionization measured during the elevation scan between 0701:28 and 0716:34 UT on 17 February 1976. Contours of ionization are at intervals of $0.2 \times 10^5 \text{ cm}^{-3}$. The trajectory of the S3-2 satellite is also indicated	6
3	Spatial variation of ionization measured during the elevation scan between 0737:37 and 0748:25 UT on 17 February 1976	7
4	Spatial variation of ionization measured during the elevation scan between 0748:25 and 0803:31 UT on 17 February 1976	8
5	Latitude variation of conductivity, electric field, and electric current measured during the elevation scan between 0748:25 and 0803:31 UT on 17 February 1976	9
6	Latitude variation of electron density at an altitude of 290 km on 17 February 1976. Measurements are from the S3-2 Langmuir probe, the S3-2 ion drift meter, and the Chatanika radar elevation scan between 0701:28 and 0716:34 UT	11
7	Variation of ion current measured by the S3-2 ion drift meter near Chatanika on 17 February 1976. The identification number of the ion sensor is indicated on each curve	12
8	Latitude variation of electron density at an altitude of 290 km on 17 February 1976	14
9	Comparison of the electric-field measurements by the S3-2 satellite and the Chatanika radar on 17 February 1976	16
10	Latitude variation of the eastward magnetic field measured by the S3-2 magnetometer on 17 February 1976. The solid line indicates the perturbation pattern	18

11	Comparison of the latitude variations of the northward current and eastward magnetic-field perturbations on 17 February 1976	20
12	The one-count sensitivity of the electron detector (ESA) on the S3-2 satellite	21
13	Altitude profile of ionization that would be produced by an electron spectrum identical to the one-count sensitivity of the electron detector on S3-2	22
14	S3-2 ground track during Revolution 1144 on 25 February 1976. The heavy solid line denotes the latitudinal extent of Chatanika radar E-region measurements at an altitude of 100 km	24
15	Spatial variation of ionization measured during the elevation scan between 0807:09 and 0815:56 UT on 25 February 1976. Contours of ionization are at intervals of $0.2 \times 10^5 \text{ cm}^{-3}$. The trajectory of the S3-2 satellite is also indicated	25
16	Spatial variation of ionization measured during the elevation scan between 0816:02 and 0824:49 UT on 25 February 1976	26
17	Spatial variation of ionization measured during the elevation scan between 0824:54 and 0833:48 UT on 25 February 1976	27
18	Latitude variation of conductivity, electric field, and electric current measured during the elevation scan between 0816:02 and 0824:49 UT on 25 February 1976	28
19	Latitude variation of electron density at an altitude of 230 km on 25 February 1976 as measured by the Chatanika radar and the S3-2 Langmuir probe and ion drift meter	30
20	Latitude variation of the eastward magnetic-field measured by the S3-2 magnetometer on 25 February 1976. The solid line indicates the perturbation pattern	31
21	Comparison of the radar and satellite measurements of electric field, northward current, and eastward magnetic field perturbation on 25 February 1976	33
22	Summary of the latitudinal variation of ionospheric electrical properties measured during Revolution 1031 on 17 February 1976	34

23	Summary of the latitudinal variation of ionospheric electrical properties measured during Revolution 1144 on 25 February 1976	35
24	Location of the seven geomagnetic observatories used in compiling the AE index	37
25	Common-scale magnetograms on 16 and 17 February 1976 for the seven locations shown in Figure 24	38
26	Common-scale magnetograms on 24 and 25 February 1976 for the seven locations shown in Figure 24	39
27	Variation of the interplanetary magnetic field (B_Z) and three geomagnetic indices (AE, K_p , Dst) on 16 and 17 February 1976	41
28	Variation of the interplanetary magnetic field (B_Z) and three geomagnetic indices (AE, K_p , Dst) on 24 and 25 February 1976	42
29	Spatial variation of ionization measured during the elevation scan between 1039:08 and 1050:36 UT on 6 February 1978	45
30	Latitudinal variation of height-integrated Pedersen conductivity measured during 22 elevation scans between 0840 and 1300 UT on 6 February 1978	47
31	Spatial variation of ionization measured during the elevation scan between 1010:57 and 1024:28 UT on 7 February 1978	48

TABLES

1	Antenna modes during Revolution 1031	3
2	S3-2/Chatanika coordinations during 1978	44

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I INTRODUCTION

A major objective in understanding the geophysical environment is to identify the distribution of ionization, electric fields, and electric currents in the high-latitude ionosphere. The spatial distribution of ionization is of interest because it affects the propagation of HF radio waves along transauroral paths. Electric currents can heat the atmosphere through joule dissipation, can change the orientation and intensity of the geomagnetic field, and may be the source of ionospheric irregularities that affect communication systems.

Although many general features of the high-latitude ionosphere have been established, we have only a rudimentary understanding of how the electron density, electric field, and electric currents are organized as a total system and how they are related to other magnetospheric and auroral parameters. This report presents the results of an investigation of the high-latitude ionosphere by comparing radar and satellite observations. Measurements of the electrical properties of the ionosphere have been made by the incoherent-scatter radar at Chatanika, Alaska, simultaneously with measurements by instrumentation on the Air Force S3-2 satellite. The ultimate objective of a coordinated analysis of these simultaneous satellite and radar measurements is to reconstruct the configuration of the electric field, currents, and conductivity at high latitudes and to deduce the pattern of these parameters in relation to ionospheric features such as the diffuse aurora, discrete auroral arcs, and the plasma trough. A previous report (Vondrak, 1979) described Chatanika/S3-2 coordinated measurements made during 1976 and 1977. At the time that report was written, the full set of S3-2 satellite data was not available for comparison with the radar data. This report presents the detailed comparison of satellite and radar data for two passes during February 1976 that were described in the previous report. These two passes were selected because they are geophysically interesting

and well suited for a comparative analysis. They were premidnight passes during which the equatorward edge of the diffuse aurora was near Chatanika; furthermore, the Chatanika radar was operated in an elevation-scan mode that determined the latitudinal variation of ionospheric electrical parameters. The next section of this report gives a detailed comparison and interpretation of the simultaneous measurements.

From January 1978 to March 1978 Chatanika operations were coordinated with intensive S3-2 operations before the satellite's reentry. The Chatanika measurements during that period are described in the third section of this report.

II MEASUREMENTS OF THE PREMIDNIGHT DIFFUSE AURORA

A. Measurements During Revolution 1031 on 17 February 1976

Figure 1 shows the S3-2 groundtrack over Alaska during Revolution 1031 on 17 February 1976. At approximately 0728 UT (2000 MLT) the satellite crossed the latitude of Chatanika at an altitude of about 300 km.

1. Chatanika Radar Measurements

During the evening of 17 February 1976, the radar was generally operated in an elevation-scan mode (Elscan) with occasional fixed-position (FP) measurements to the northeast and to the northwest at an elevation of 60° . The last complete elevation scan prior to the S3-2 pass was made from 0701:28 to 0716:34 UT. A partial scan was made from 0716:39 to 0721:06 UT. The radar was pointed to the northeast from 0722:36 to 0728:26 UT and to the northwest from 0731:37 to 0736:37 UT. The antenna was pointed in the directions listed in Table 1 during and near the time of the S3-2 pass.

Table 1

ANTENNA MODES DURING REVOLUTION 1031

Time (UT)	Mode	Azimuth (degrees)	Elevation (degrees)
0701:28 to 0716:34	Elscan	29	155 to 15
0716:39 to 0721:05	Elscan	29	15 to 60
0722:36 to 0728:26	FP	74	60
0731:37 to 0736:37	FP	344	60
0737:37 to 0748:25	Elscan	29	60 to 155
0748:25 to 0803:31	Elscan	29	155 to 15

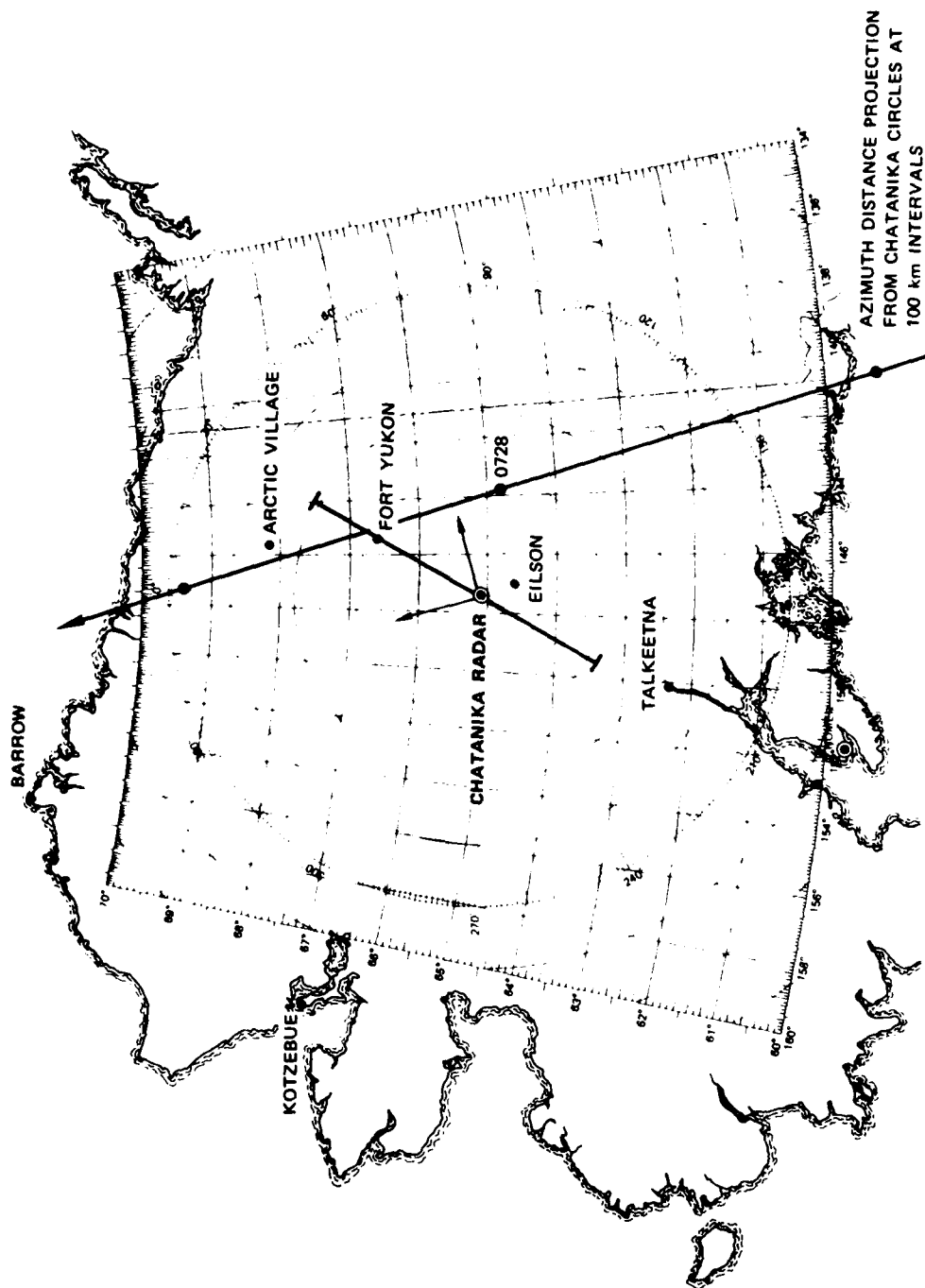


FIGURE 1 S3-2 GROUND TRACK DURING REVOLUTION 1031 ON 17 FEBRUARY 1976. The heavy solid line denotes the latitudinal extent of E-region measurements at the 100-km altitude. The pointing directions while the radar is in the fixed-position mode are also indicated.

The spatial variation of electron density measured during the elevation scan from 0701:28 to 0716:34 UT is shown in Figure 2. In this figure, as well as the other contour plots in this report, the electron density is shown as a function of altitude and geomagnetic invariant latitude. Geomagnetic field lines are vertical in such a representation. The equatorward edge of the diffuse aurora is visible overhead at Chatanika, with E-region ionization increasing at greater distances north. An auroral arc is possibly present at the northern horizon (69° latitude). Features of interest in the F-region (above 200 km) include regions of structured ionization over the equatorward edge of the diffuse aurora. Also apparent is the poleward displacement of 200 km (2° of latitude) between E-region ionization and the comparable density of ionization in the F-region.

The trajectory of the S3-2 satellite projected into the Chatanika meridional plane is indicated in Figure 2. The satellite moved northwards at an altitude of about 300 km.

The temporal stability of the auroral ionization can be determined from successive radar measurements. As indicated in Table 1, the radar was in a fixed-position mode during the S3-2 pass at 0728 UT. Approximately 11 min after the satellite pass, the partial scan shown in Figure 3 began. This scan was followed by a horizon-to-horizon scan between 0748:25 UT and 0803:31 UT (Figure 4). The E-region contours (80- to 200-km altitude) are similar in both magnitude and latitudinal location in the three scans shown in Figures 2 to 4. The only conspicuous change during this period occurs in the F-region. The equatorward boundary of enhanced ionization moves southward between the end of the scan in Figure 2 and that in Figure 3. For example, at an altitude of 300 km, the southernmost boundary of ionization exceeding $4 \times 10^4 \text{ cm}^{-3}$ is at 66.6° geomagnetic latitude in Figure 2, and at 65° in Figure 3.

Figure 5 shows the latitudinal variation of conductivity, electric field, and electric current during the first full scan after the satellite pass. The electric field was measured in the trough to the south, but accurate determination of its value is not possible

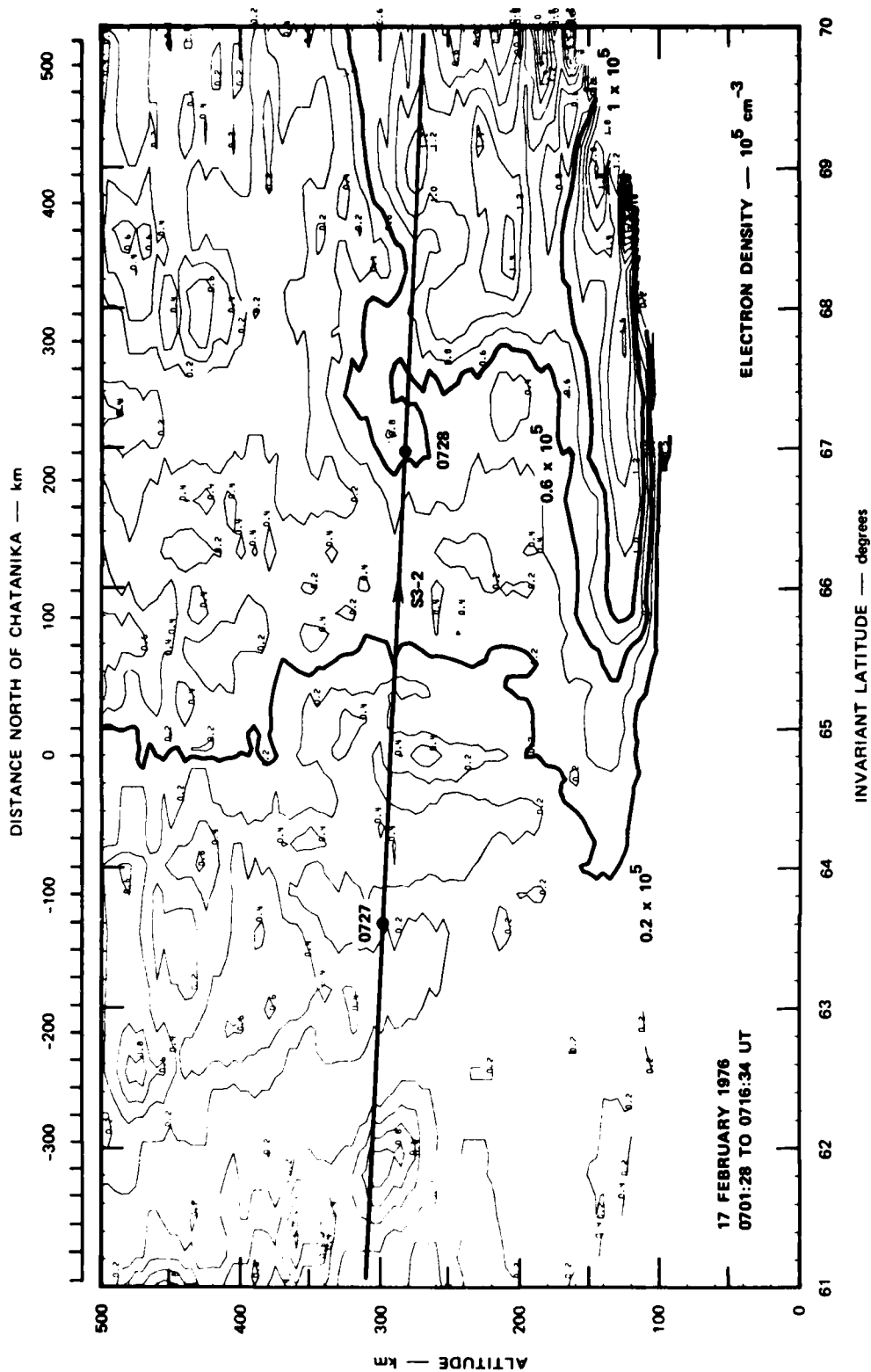


FIGURE 2 SPATIAL VARIATION OF IONIZATION MEASURED DURING THE ELEVATION SCAN BETWEEN 0701:28 AND 0716:34 UT ON 17 FEBRUARY 1976. Contours of ionization are at intervals of $0.2 \times 10^5 \text{ cm}^{-3}$. The trajectory of the S3-2 satellite is also indicated.

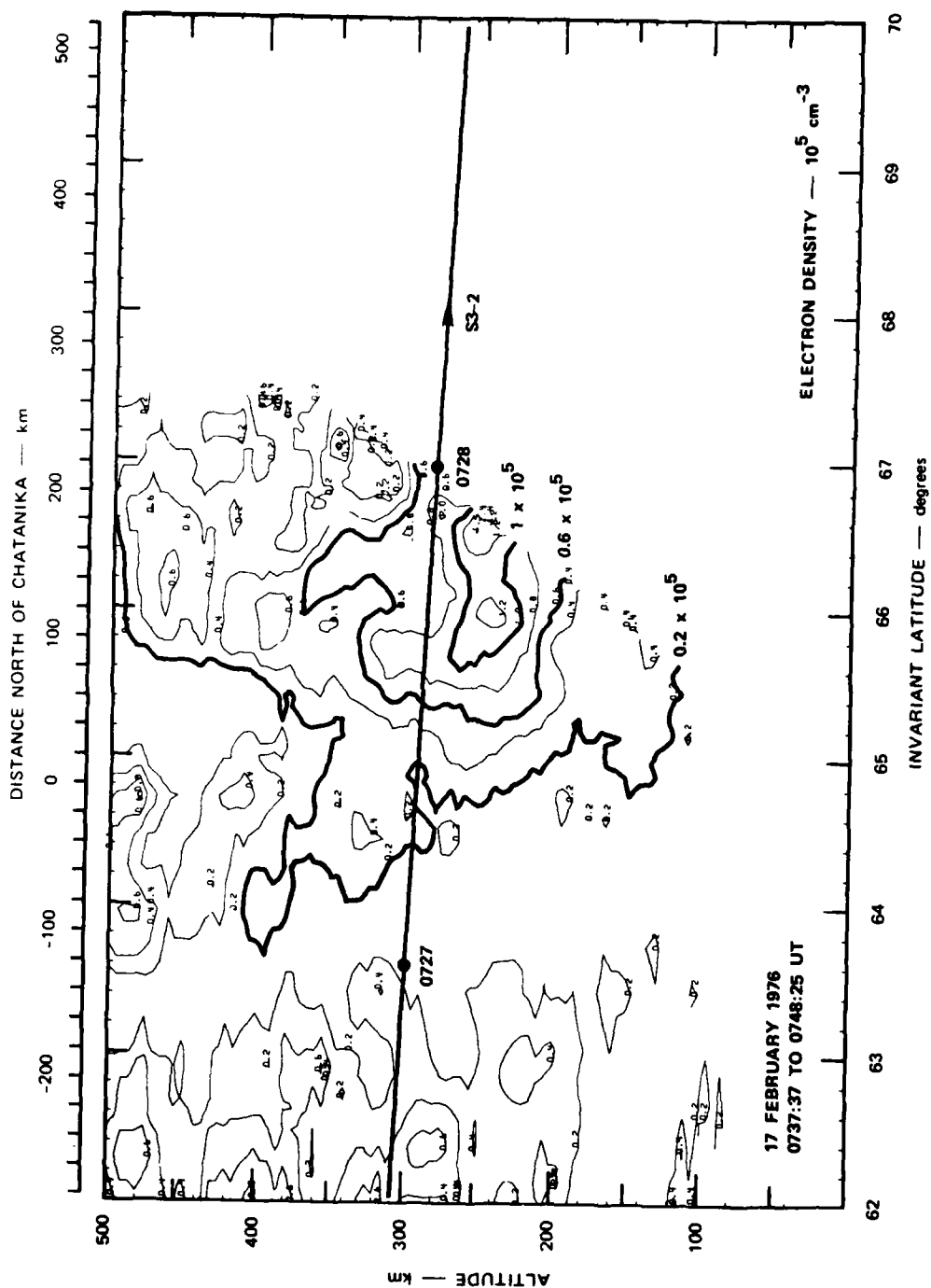


FIGURE 3 SPATIAL VARIATION OF IONIZATION MEASURED DURING THE ELEVATION SCAN BETWEEN 0737:37 AND 0748:25 UT ON 17 FEBRUARY 1976

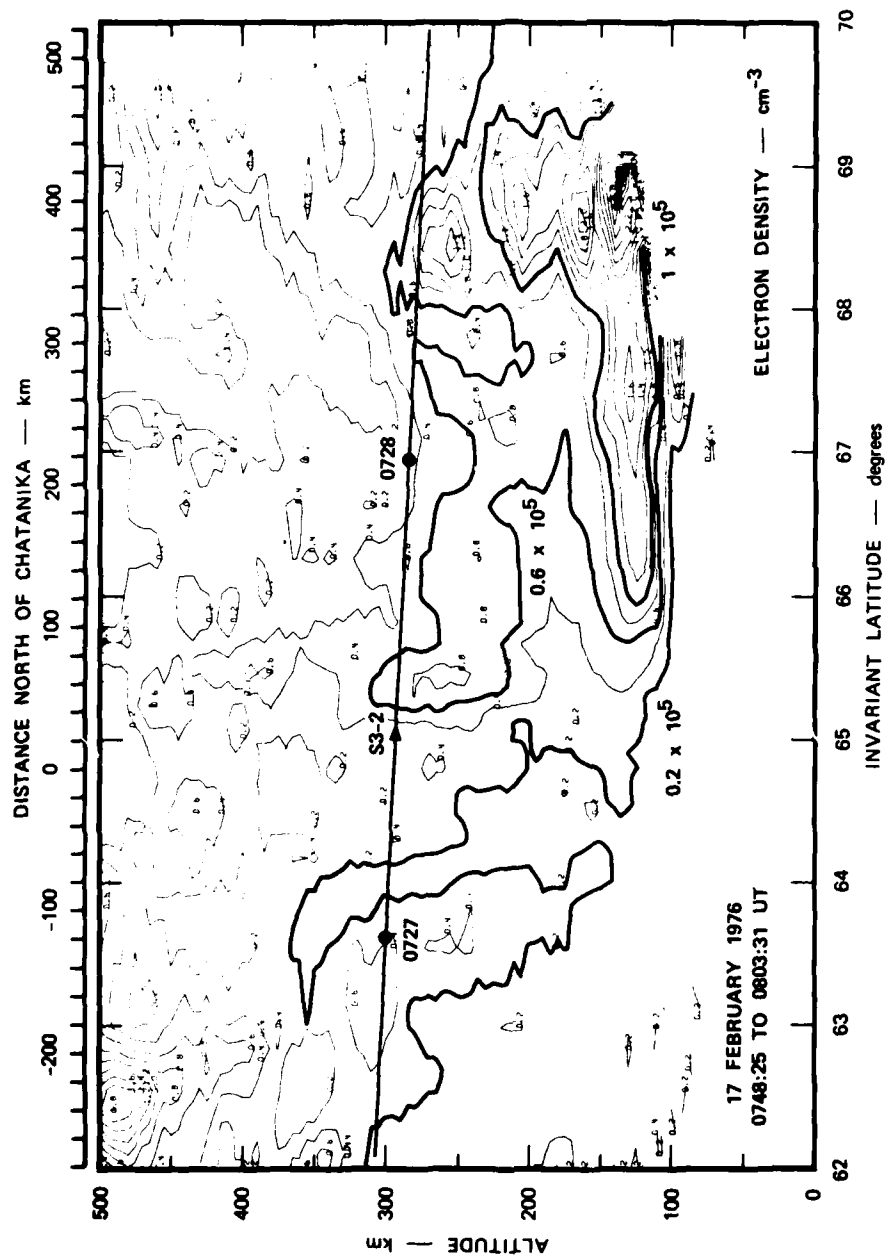


FIGURE 4 SPATIAL VARIATION OF IONIZATION MEASURED DURING THE ELEVATION SCAN BETWEEN 0748:25 AND 0803:31 UT ON 17 FEBRUARY 1976

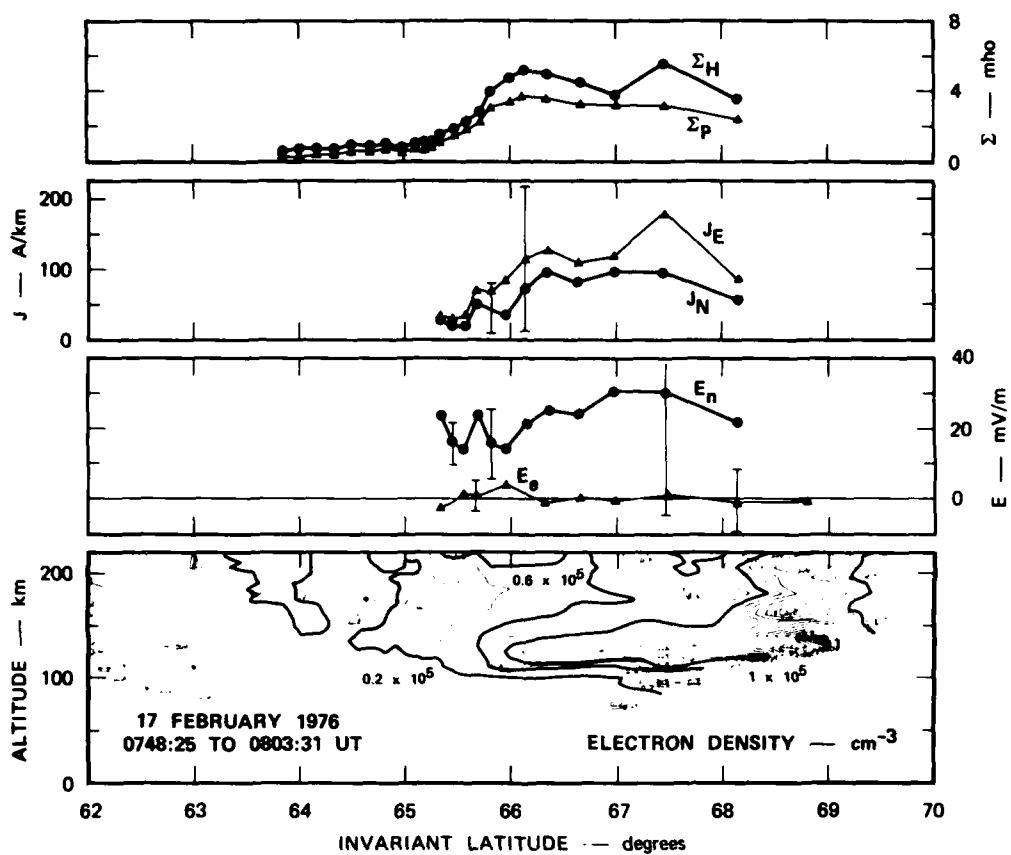


FIGURE 5 LATITUDE VARIATION OF CONDUCTIVITY, ELECTRIC FIELD, AND ELECTRIC CURRENT MEASURED DURING THE ELEVATION SCAN BETWEEN 0748:25 AND 0803:31 UT ON 17 FEBRUARY 1976

because of the small electron density there. The error bars given for the electric field and current are based on a conservative estimate of the accuracy of the radar measurements of plasma velocity. The actual experimental errors are probably smaller, as indicated by the general regularity of the data. In the diffuse aurora the electric field was primarily northwards and the current was directed to the northeast.

2. S3-2 Plasma-Density and Temperature Measurements

Figure 6 shows the thermal electron measurements made by the spherical Langmuir probe on the S3-2 satellite when it crossed the region near the geomagnetic latitude of Chatanika. These plasma-density measurements have been corrected for effects of the satellite potential.

For comparison, we also show in Figure 6 the latitudinal variation of electron density at 290 km measured by the Chatanika radar. These densities were measured with a 320- μ s pulse, which has a spatial range resolution of 48 km. The radar measurements have been corrected for the plasma effects described in the previous report (Vondrak, 1979).

The radar measurements generally exceed the Langmuir probe measurements by a factor of 2 in the trough and more than a factor of 4 in the diffuse aurora.

In an attempt to reconcile these two data sets, we compared them to the plasma density inferred from the ion drift meter on S3-2. This experiment consists of two arrays of four passive thermal ion sensors, each with a circular aperture area, a , of 6.82 cm^2 . The ambient plasma density, n , can be computed from the ion current, I , when the sensors rotate into the ram direction (F. Rich, private communication). In that case,

$$n(\text{cm}^{-3}) = \frac{I}{e \cdot a \cdot \epsilon \cdot v} = 1.5 \times 10^{12} I(\text{A})$$

where e is the electron charge, ϵ is the transmission efficiency (78%), and v is the satellite velocity (7.8 km/s). Examples of the ion current measured by the ion drift meter sensors over Chatanika are shown in Figure 7.

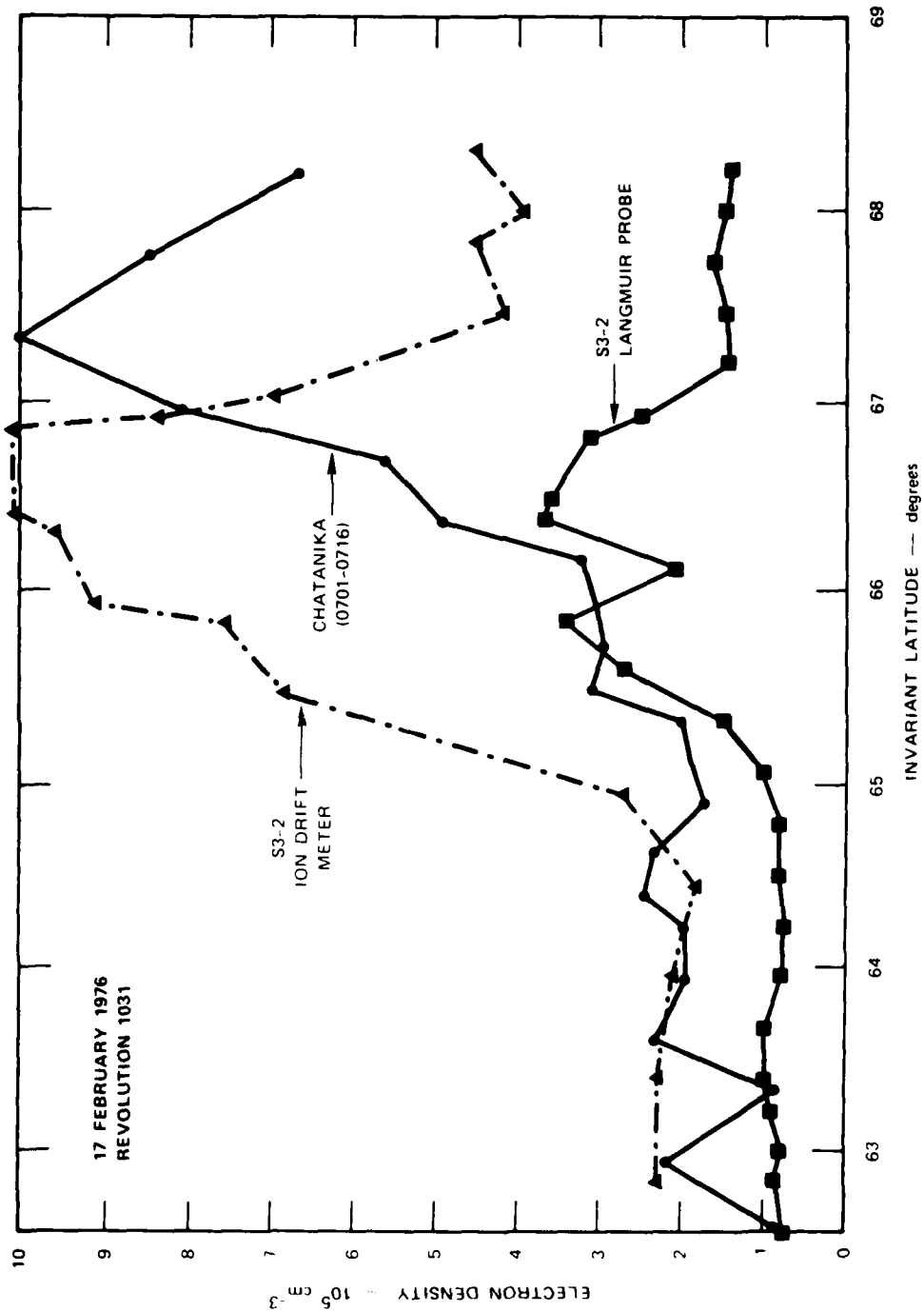


FIGURE 6 LATITUDE VARIATION OF ELECTRON DENSITY AT AN ALTITUDE OF 290 km ON 17 FEBRUARY 1976. Measurements are from the S3-2 Langmuir probe, the S3-2 ion drift meter, and the Chatanika radar elevation scan between 0701:28 and 0716:34 UT.

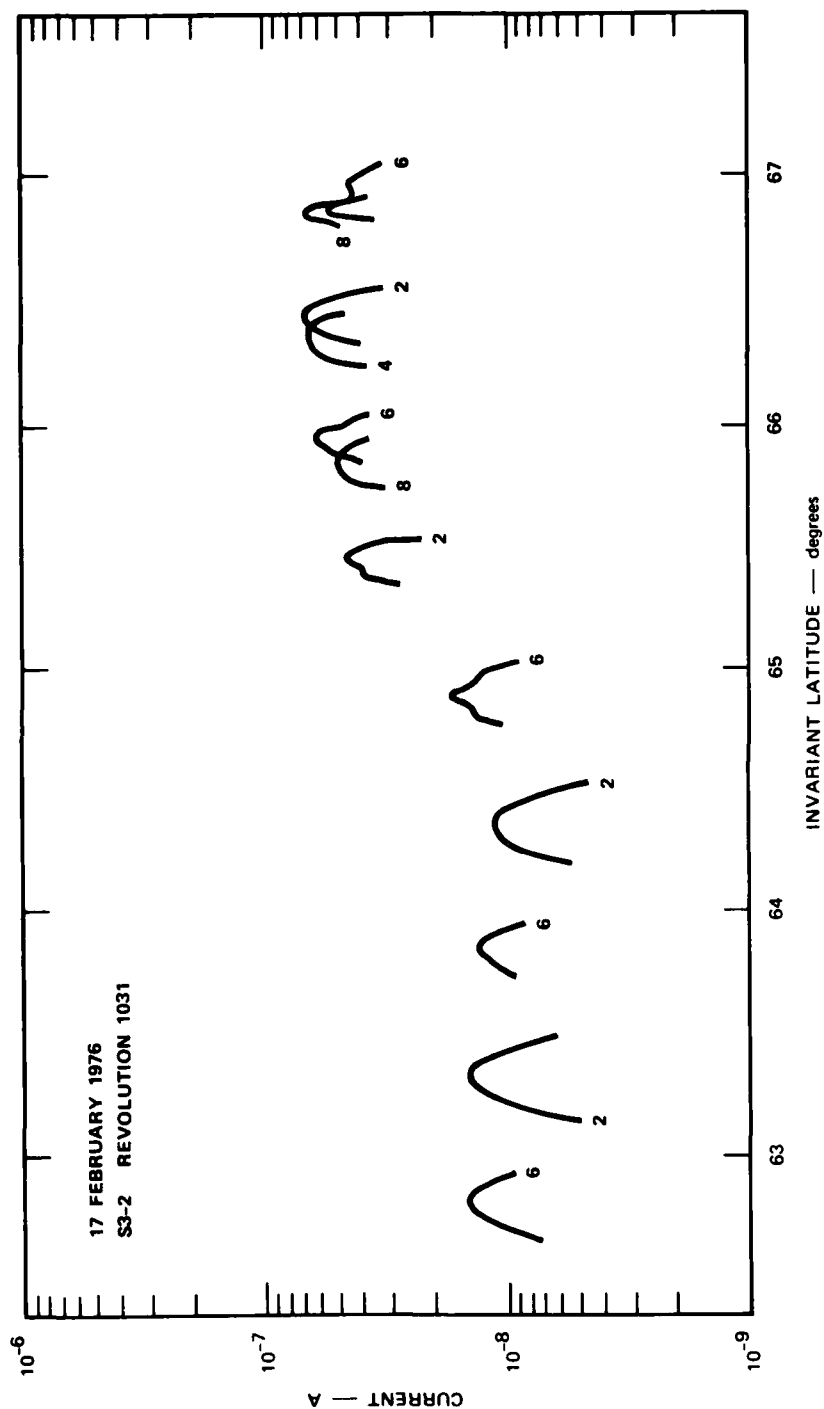


FIGURE 7 VARIATION OF ION CURRENT MEASURED BY THE S3-2 ION DRIFT METER NEAR CHATANIKA ON 17 FEBRUARY 1976. The identification number of the ion sensor is indicated on each curve.

The plasma density computed from the drift meter current is shown in Figure 6. The measurements in the trough agree well with the Chatanika radar measurements. Also similar enhancements are seen in the diffuse aurora; in both data sets the density increases from about $2 \times 10^4 \text{ cm}^{-3}$ to 10^5 cm^{-3} in a latitudinal distance of about 180 km. This increase indicates a northward gradient in plasma density of about 440 electrons cm^{-3}/km . The only difference between the radar and ion sensor data is an approximate 1° latitudinal shift in the location of the equatorward edge of the enhancement at satellite altitude. This difference is not an artifact of the methods used to calculate geomagnetic latitude from geographical coordinates. The methods used at SRI and at the Air Force Geophysics Laboratory (AFGL) agree to within 0.2° in latitude (20 km).

This discrepancy in the equatorial boundary of the ionization enhancement is thought caused by the equatorward motion of the F-region during the 19 min separation between the two measurements. Evidence for this motion is found by examining the temporal variations in the radar measurements. A comparison of the ionization contours along the satellite trajectory in Figures 2 and 3 shows that the F-region above the diffuse aurora moved southward just before the satellite pass. In the fixed position between 0722:36 and 0728:26 UT, during the satellite pass, the radar measurement at the 290-km altitude was at an invariant latitude of 66.0° . The ionization at this altitude varied between 7.0 and $8.6 \times 10^4 \text{ cm}^{-3}$, with the largest value recorded between 0727:41 and 0728:26 UT. These values are indicated in Figure 8 along with the latitudinal measurements made during the two partial scans just before and after the satellite pass. The F-region was displaced southward between 0716 and 0722 UT, and later radar measurements agree well with the simultaneous ion-drift-meter data. The reason for this disagreement between the Langmuir probe measurements and the measurements by the radar and ion-drift meter is uncertain. It may result from an aliasing of the data by a vehicle potential systematically more negative (by approximately 0.2 V) than that calculated from the swept voltage data (F. Rich, private communication).

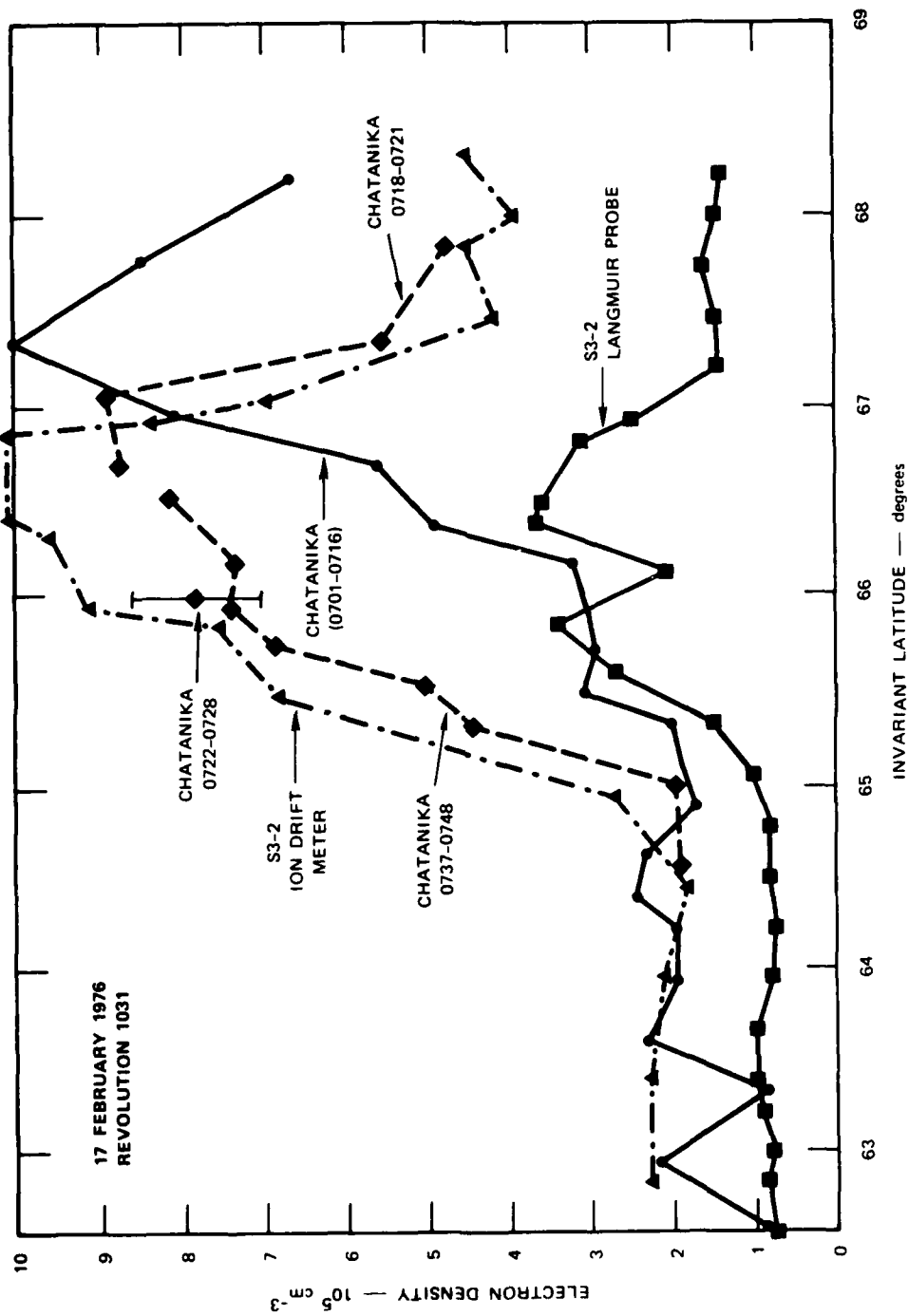


FIGURE 8 LATITUDE VARIATION OF ELECTRON DENSITY AT AN ALTITUDE OF 290 km ON 17 FEBRUARY 1976

The ion and electron temperatures can be derived from the incoherent-scatter measurements at satellite altitude. The ionospheric temperature measurements require a longer integration time than the density measurements, so reliable values are obtained only while the radar is in a fixed position during this pass. Between 0722:36 and 0728:36 UT, the radar measurements in the 48-km long range gate centered at the 286-km altitude indicated that the electrons and ions were isothermal with a temperature of $980^{\circ} \pm 55^{\circ}$. A similar result was found in the fixed position to the northwest; both locations correspond to a latitude of about 66° . The S3-2 spherical Langmuir probe measured electron temperature every 32 s. The electron temperatures near Chatanika were 2902 K at 64.9° latitude, 2243 K at 66.6° latitude, and 1871 K at 67.5° latitude. Why the satellite Langmuir probe measurements indicate temperatures so much larger than radar measurements is unknown.

3. S3-2 Electric-Field Measurements

The primary electric-field monitor on the S3-2 satellite was a 27.4-m dipole in the spacecraft spin plane. The component of the electric field in the trajectory plane, referred to as E_{forward} or, as here, E_F , is determined from the variation of the measured potential between the spinning dipole.

In Figure 9 shows the latitudinal variation of E_F compared with the nearly simultaneous measurements of the vector electric field by the Chatanika radar. The agreement is reasonably good between the two measuring techniques in the region of simultaneous measurements. For example, in the diffuse aurora between 66° and 68° latitude, the radar-measured electric field was about 25 mV/m and directed northward. In this region, the angle between the satellite velocity vector and the geomagnetic meridian was about 45° , so that projection of the electric-field vector onto the trajectory plane was about 20 mV/m.

The satellite data show that the northward electric field extended at least 2° equatorward of the diffuse aurora. Also the electric field appears to increase near the auroral arc at 69° latitude.

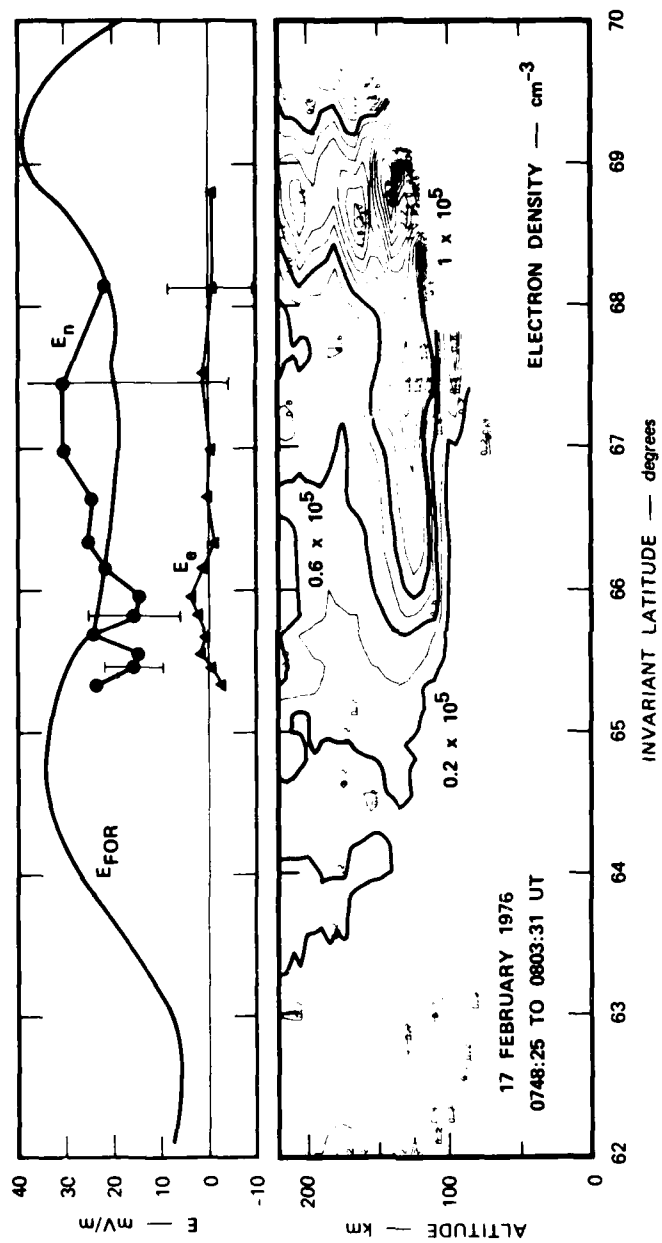


FIGURE 9 COMPARISON OF THE ELECTRIC-FIELD MEASUREMENTS BY THE S3-2 SATELLITE AND THE CHATANIKA RADAR ON 17 FEBRUARY 1976

4. S3-2 Magnetic-Field Measurements

The magnetic field was measured on the S3-2 spacecraft by a triaxial fluxgate magnetometer. Nominally, one axis of the magnetometer is parallel to the satellite's spin axis and the other two axes are in the spin plane. The primary use of the vector magnetic-field data is to determine the location and magnitude of electric currents flowing parallel to the earth's magnetic field (field-aligned currents).

The magnetic-field-perturbation components measured near Chatanika on Revolution 1031 are shown in Figure 10. The general pattern of the east-west perturbations is an eastward deflection of about 200 nT in the latitudinal interval of 64.5° to 68.8° and a return to baseline near 70° . The eastward magnetic field has a gradient of about 0.17 nT/km in the diffuse aurora over Chatanika. The magnetic-field gradient is related to the field-aligned current by the expression

$$\nabla \times \vec{B} = \mu_0 \vec{j}$$

or

$$\frac{\partial B_x}{\partial y} = -\mu_0 j_{11}$$

where x and y are magnetic east and north and j_{11} is the vertical current. We have assumed that there are no eastward derivatives of the horizontal current. With this relationship, we find that the field-aligned current intensity above the diffuse aurora is about $0.14 \mu\text{A}/\text{m}^2$, directed downward.

The field-aligned current is related to the horizontal current by

$$\nabla \cdot \vec{j} = 0$$

This implies that

$$\frac{\partial j_y}{\partial x} = j_{11}$$

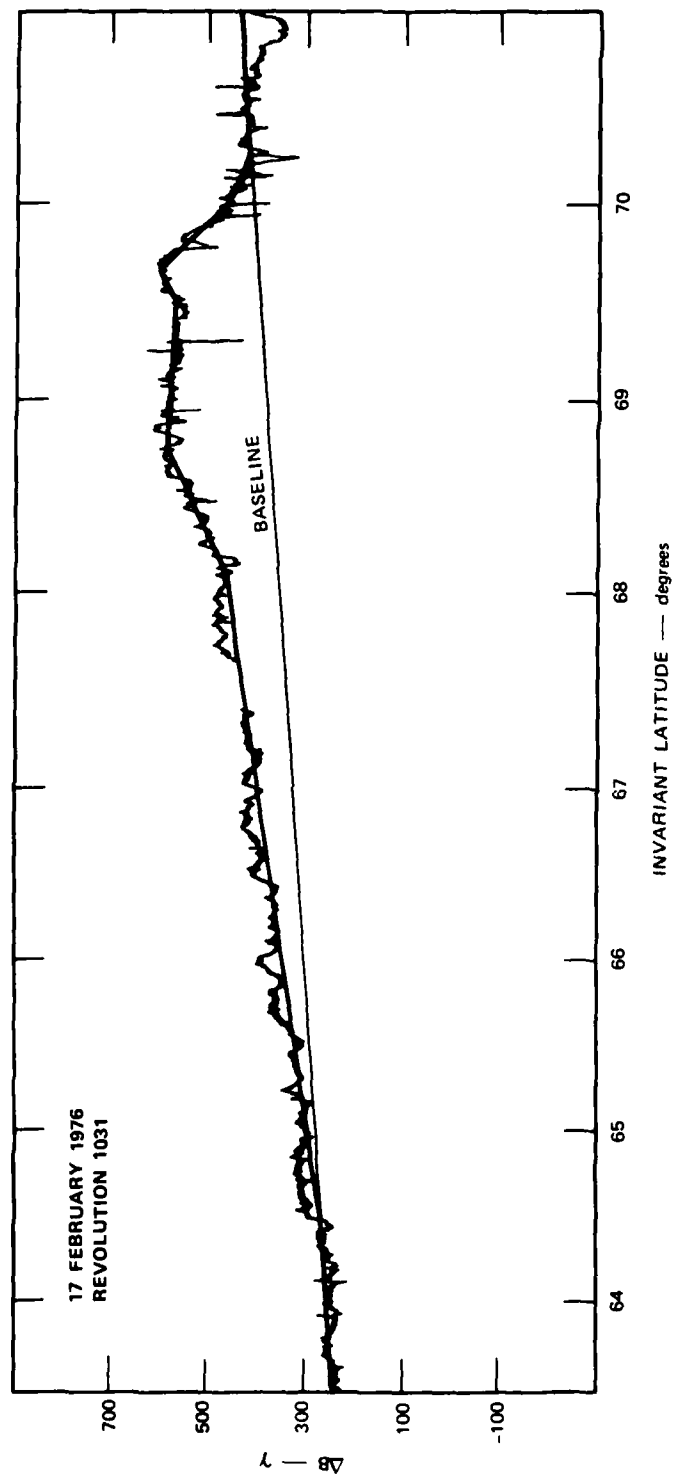


FIGURE 10 LATITUDE VARIATION OF THE EASTWARD MAGNETIC FIELD MEASURED BY THE S3-2 MAGNETOMETER ON 17 FEBRUARY 1976. The solid line indicates the perturbation pattern.

or

$$j_y = \int j_{11} dy \quad .$$

With this assumption, the latitudinal variation of the horizontal closing current is shown in Figure 11. Reasonably good agreement with the northward current is found within the diffuse aurora.

5. S3-2 Energetic Electron Measurements

Electrons with energies between 0.08 and 17 keV were measured by a parallel plate electrostatic analyzer (ESA) on S3-2. The instrument geometric factor was $4.68 \times 10^{-5} \text{ cm}^2\text{-sr}$, with a $\Delta E/E$ of 0.419. The instrument produced a 32-point energy spectrum only a second. The one-count sensitivity of the instrument, including channeltron efficiency, is shown in Figure 12 (D. Hardy, private communication).

Examination of the electron flux measurements near Chatanika showed no indication of the diffuse aurora discernable above the instrument background of approximately two counts per channel. This insensitivity to the electron fluxes in the diffuse aurora is apparently caused by the small geometric factor of the ESA. To evaluate the instrument sensitivity, we computed the ionization profile produced by an electron beam with an energy spectrum the same as the detector one-count sensitivity. As shown in Figure 13, profiles were calculated both for an electron beam having only the energy range of the ESA and for a beam that has a distribution extending to 50 keV. Both profiles have E-region densities much greater than those observed in the diffuse aurora. Therefore, it is not surprising that no signature of the diffuse aurora was apparent in the ESA data near Chatanika. As a result, the radar-ionization measurements and the satellite electron-flux data could not be compared.

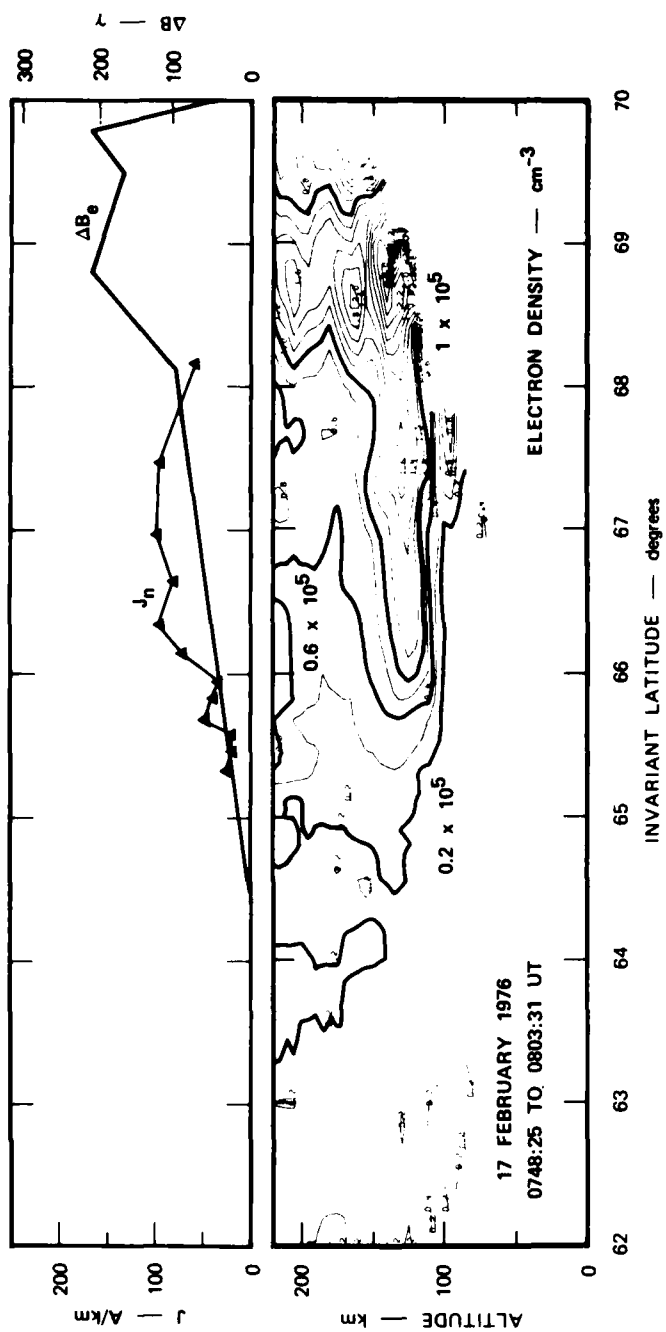


FIGURE 11 COMPARISON OF THE LATITUDE VARIATION OF THE NORTHWARD CURRENT AND EASTWARD MAGNETIC-FIELD PERTURBATIONS ON 17 FEBRUARY 1976

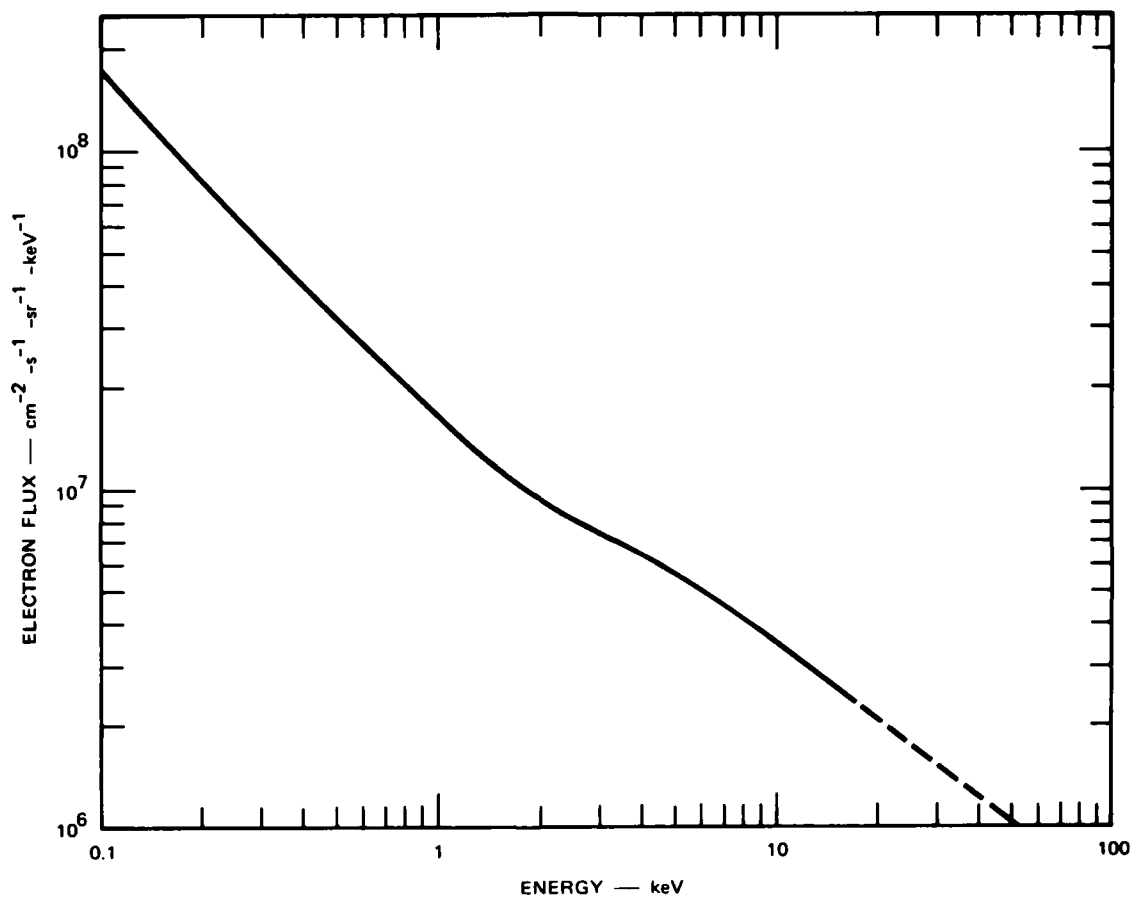


FIGURE 12 THE ONE-COUNT SENSITIVITY OF THE ELECTRON DETECTOR (ESA) ON THE S3-2 SATELLITE

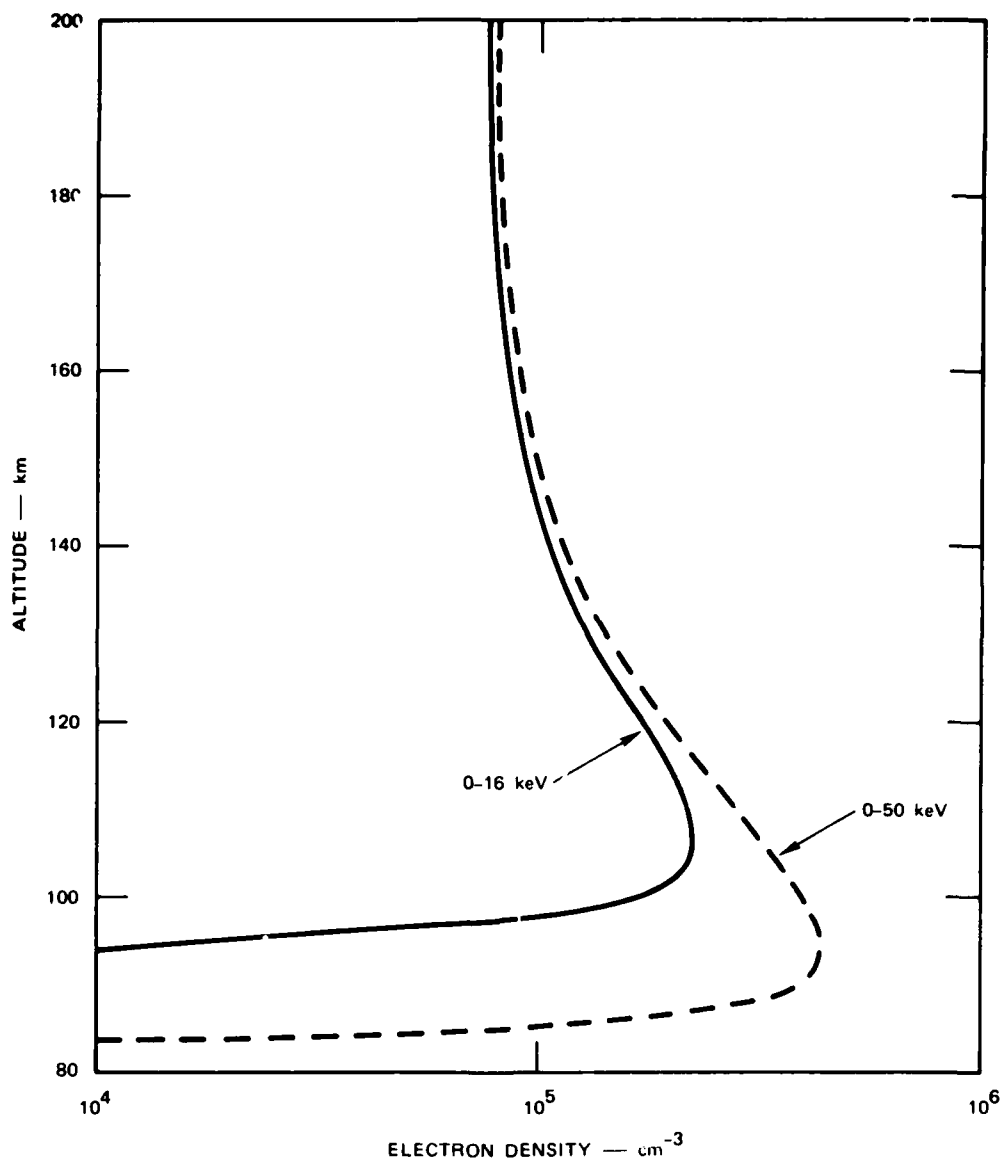


FIGURE 13 ALTITUDE PROFILE OF IONIZATION THAT WOULD BE PRODUCED BY AN ELECTRON SPECTRUM IDENTICAL TO THE ONE-COUNT SENSITIVITY OF THE ELECTRON DETECTOR ON S3-2

4. Measurements During Revolution 1144 on 25 February 1976

The S3-2 pass on 25 February 1976 is the second example of simultaneous radar and satellite measurements of ionospheric electrodynamics in the pre-midnight diffuse aurora.

The S3-2 groundtrack over Alaska during Revolution 1144 is shown in Figure 13. At approximately 0817 UT (2100 MLT) the satellite crossed the latitude of Chatanika at an altitude of about 245 km.

1. Chatanika Radar Measurements

During the S3-2 pass on 25 February 1976 the Chatanika radar was operated in a continuous scan between the geomagnetic zenith and the northern horizon. The E-region (the 100-km altitude) latitudinal extent of the scan limits is shown in Figure 14.

The latitudinal variation of the electron density measured during the elevation scan prior to the S3-2 pass is shown in Figure 15. The main trough was overhead at Chatanika and the equatorward edge of the diffuse aurora was about 100 km north of Chatanika. The S3-2 trajectory is also indicated in the figure.

The temporal stability of the auroral ionization can be determined by comparing the measurements in Figure 5 with those during the next two scans (Figure 16 and 17). It can be seen that the ionization morphology is quite steady during the 26-min period centered around the satellite pass, in both the E-region and the F-region.

The latitudinal variation of the ionospheric conductivity, electric field, and electric current during the scan simultaneous with the S3-2 pass are shown in Figure 18. Both the electric field and the electric current were directed northeastward. There were large gradients in the conductivities and both components of the electrojet at the equatorward edge of the diffuse aurora.

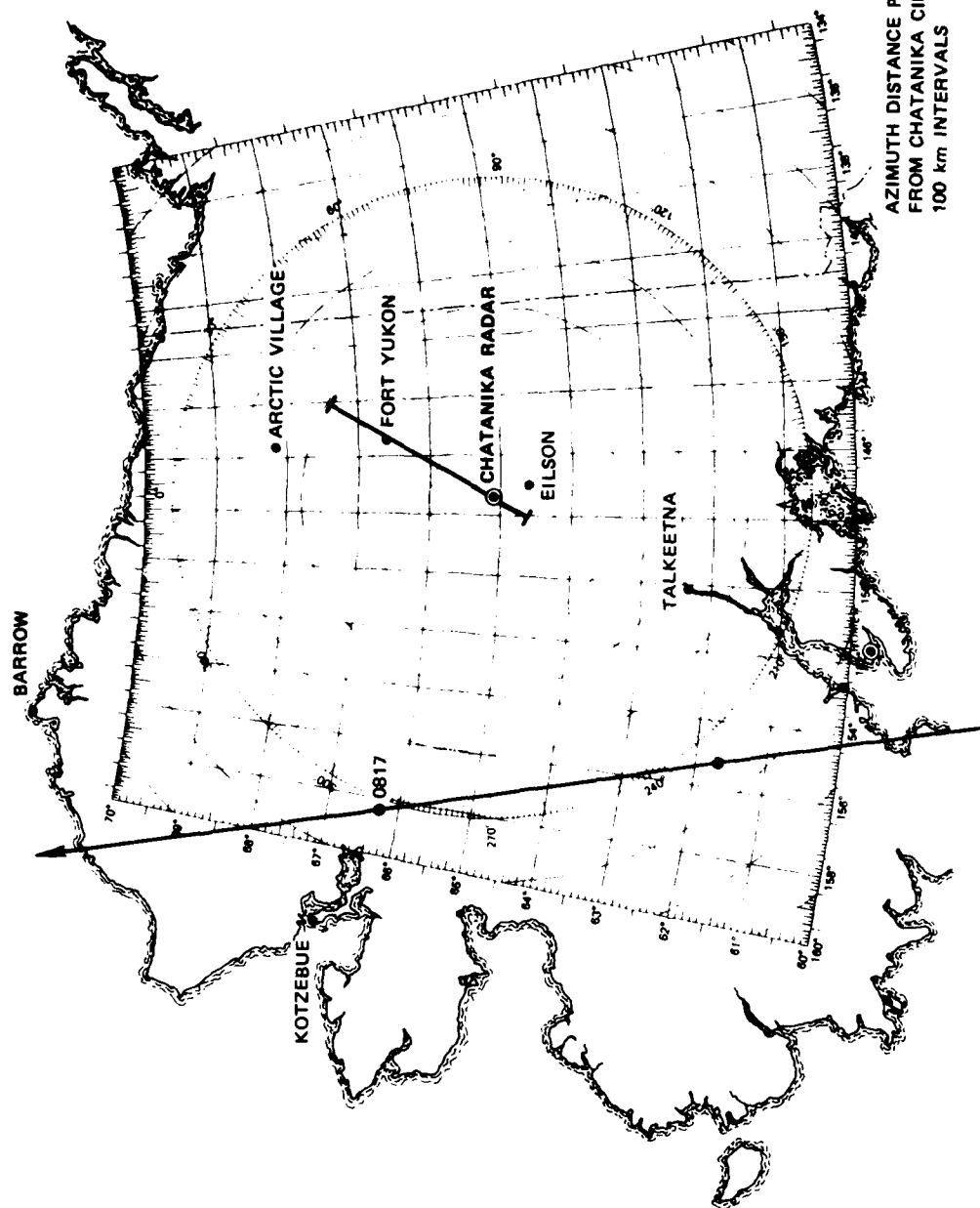


FIGURE 14 S3-2 GROUND TRACK DURING REVOLUTION 1144 ON 25 FEBRUARY 1976. The heavy solid line denotes the latitudinal extent of Chatanika radar E-region measurements at an altitude of 100 km.

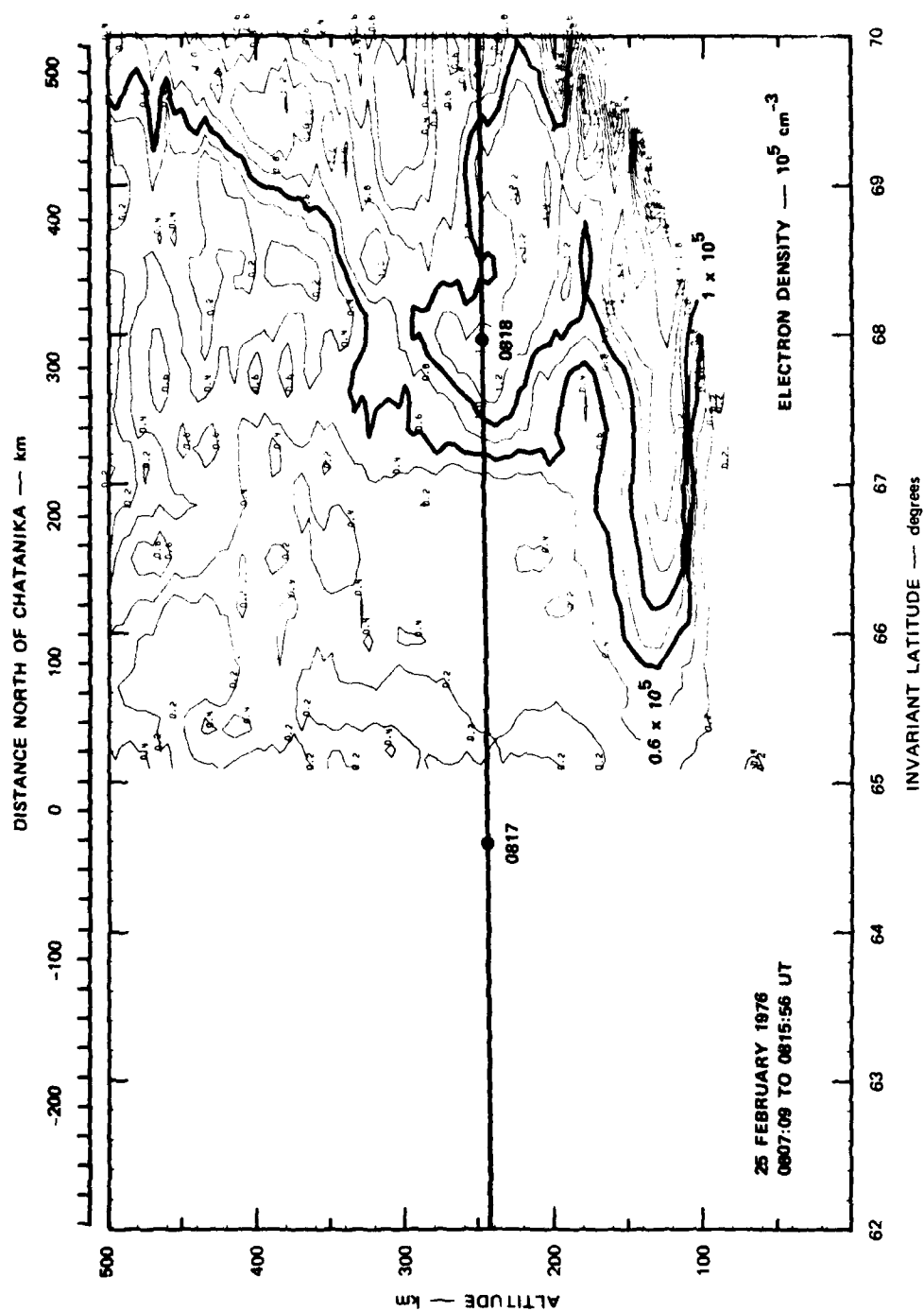


FIGURE 15 SPATIAL VARIATION OF IONIZATION MEASURED DURING THE ELEVATION SCAN BETWEEN 0807:09 AND 0815:56 UT ON 25 FEBRUARY 1976. Contours of ionization are at intervals of $0.2 \times 10^5 \text{ cm}^{-3}$. The trajectory of the S3-2 satellite is also indicated.

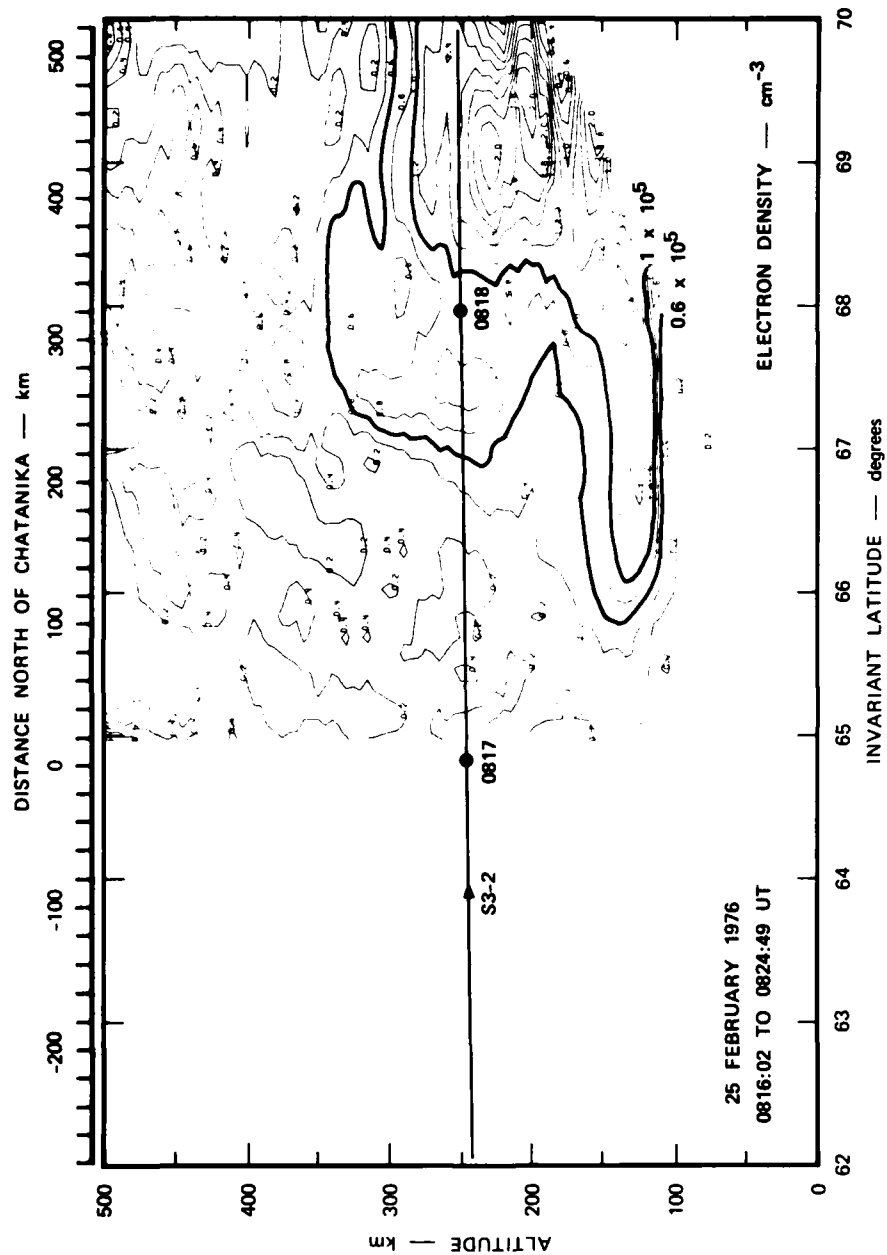


FIGURE 16 SPATIAL VARIATION OF IONIZATION MEASURED DURING THE ELEVATION SCAN BETWEEN 0816:02 AND 0824:49 UT ON 25 FEBRUARY 1976

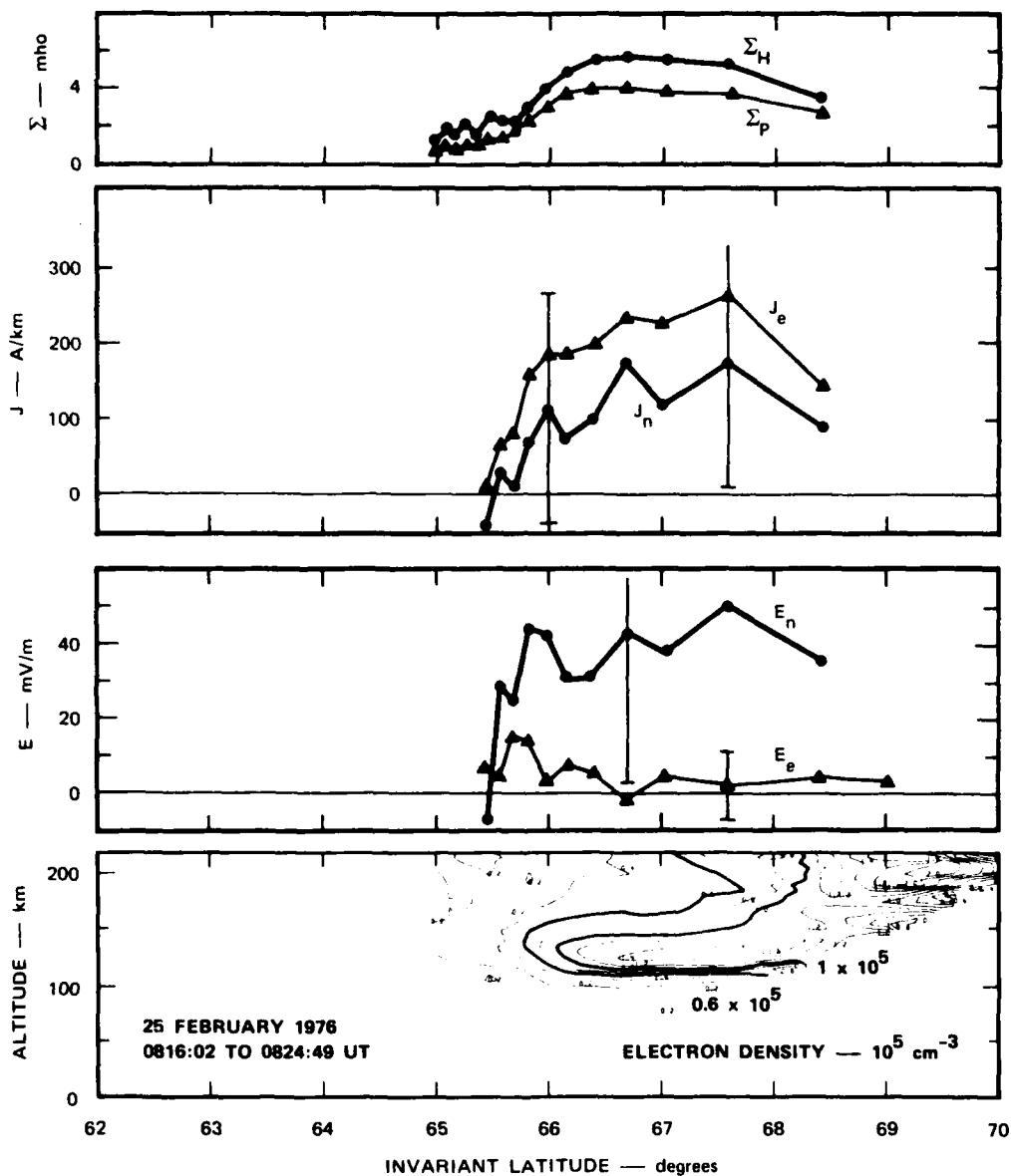


FIGURE 18 LATITUDE VARIATION OF CONDUCTIVITY, ELECTRIC FIELD, AND ELECTRIC CURRENT MEASURED DURING THE ELEVATION SCAN BETWEEN 0816:02 AND 0824:49 UT ON 25 FEBRUARY 1976

2. S3-2 Satellite Measurements

Electron-density measurements by the spherical Langmuir probe on S3-2 are shown in Figure 19. For comparison, we also show the Chatanika radar measurements at the same geomagnetic latitudes at an altitude of 230 km. The differences are substantial between the radar and Langmuir probe measurements. To investigate the discrepancy between the two measurements, we derived the electron density from the S3-2 ion-drift-meter data in the same way as for revolution 1031. These measurements are also shown in Figure 19. They agree well with the radar measurements, except for a displacement in latitude of approximately 1.5° .

The source of this displacement was sought by first examining the temporal variations in the auroral ionization (Figures 15 to 17). Little variation is apparent, indicating that motion of the auroral F-region ionization is not an obvious source of the displacement.

The displacement is thought to be a real spatial variation, resulting from the longitudinal separation between the satellite trajectory and the Chatanika meridian. As shown in Figure 14, the satellite passed the Chatanika latitude about 500 km to the west, or about 0.9 hour earlier in MLT. It is well known that in the evening sector, the equatorward auroral boundary occurs at lower latitudes at later local times. For example, Gussenhoven et al., (1981) found that at 2030 MLT the average equatorward boundary occurred 1.8° further south than at 1930 MLT. Also, Akasofu et al. (1972) used all-sky camera photographs to determine that auroral arcs at 2000 MLT are aligned with a tilt of about 1° to 2° per hour of MLT. Therefore, this tilt of the auroral oval in local time is a plausible explanation for the latitudinal offset between the radar and satellite measurements.

The S3-2 measurements of the magnetic-field perturbation is shown in Figure 20. The east-west component shows a large deflection at the 66.4° latitude, indicating the equatorward boundary of a downward current sheet. The poleward edge of this downward current sheet is not well defined. It either ends or decreases in density at 67.1° N.

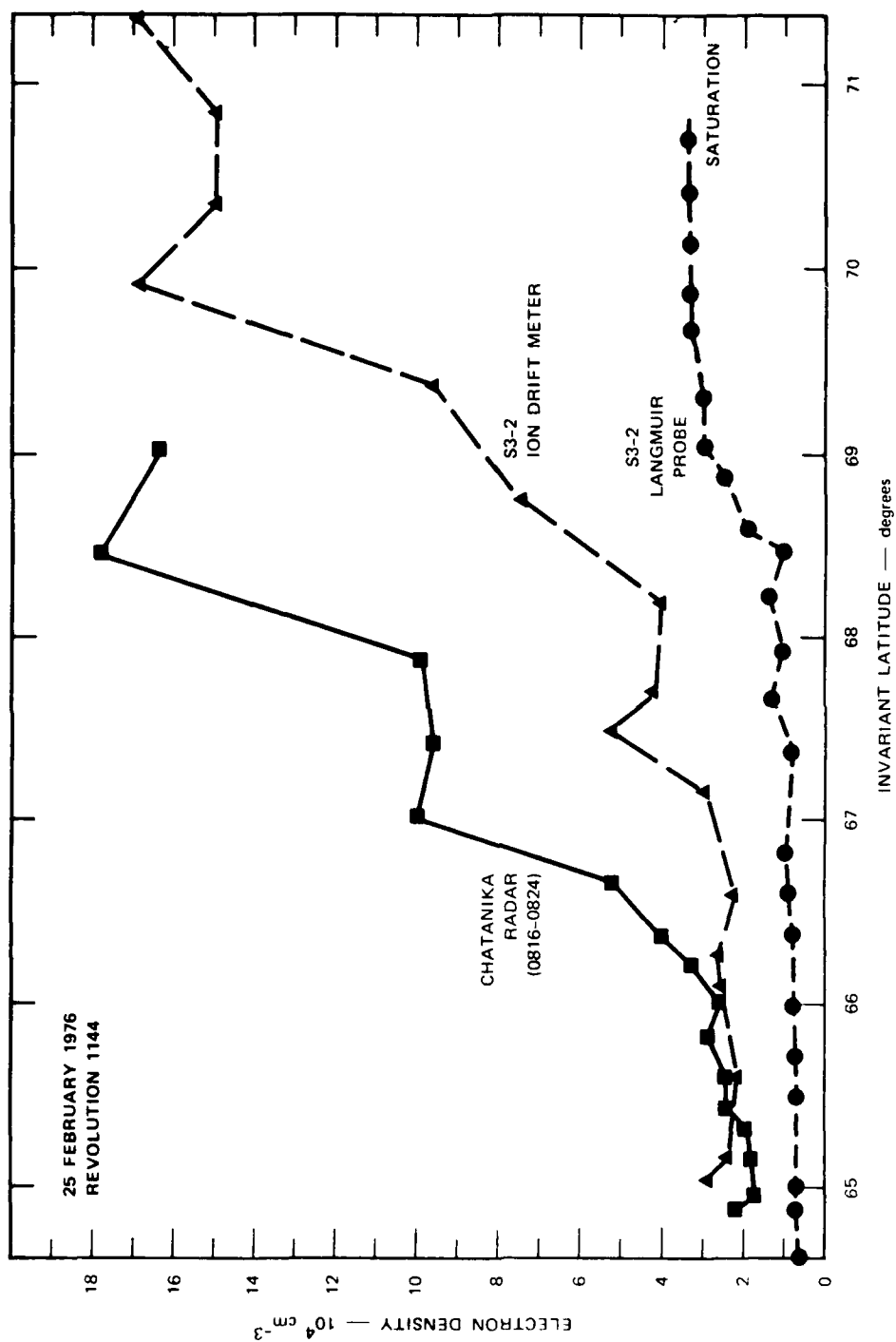


FIGURE 19 LATITUDE VARIATION OF ELECTRON DENSITY AT AN ALTITUDE OF 230 km ON 25 FEBRUARY 1976 AS MEASURED BY THE CHATANIKA RADAR AND THE S3-2 LANGMUIR PROBE AND ION DRIFT METER

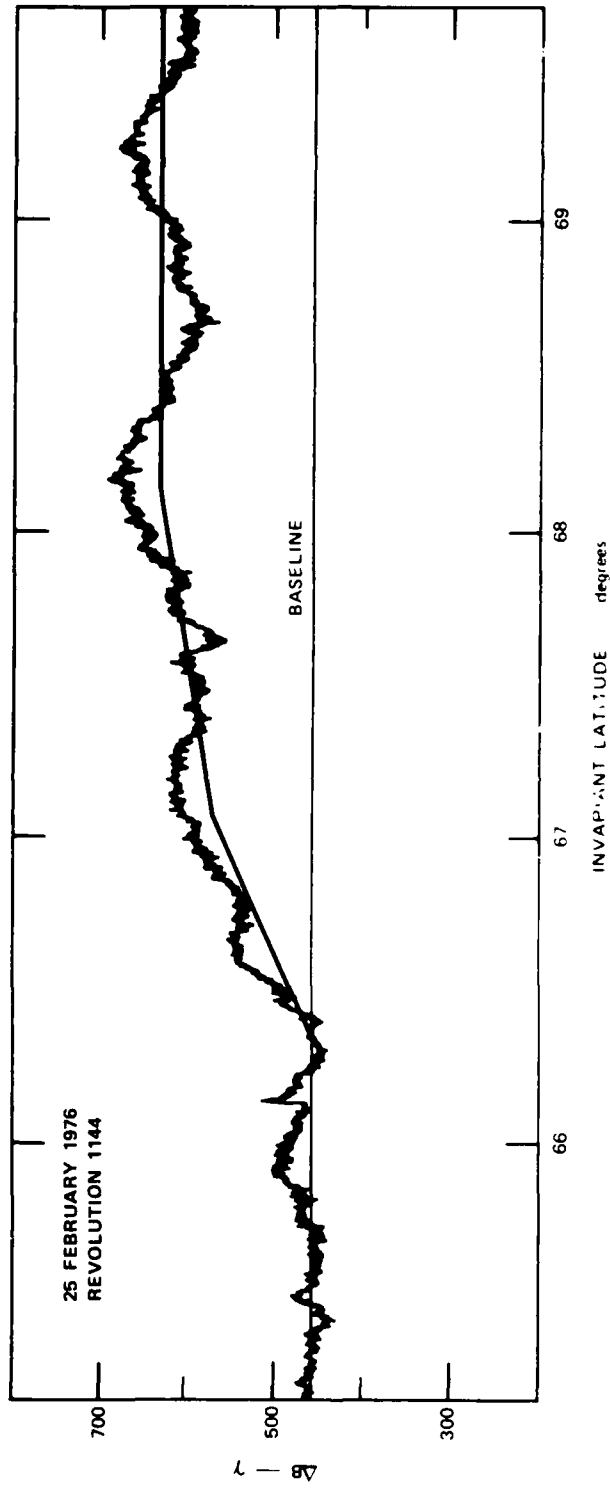


FIGURE 20 LATITUDE VARIATION OF THE EASTWARD MAGNETIC-FIELD VARIATION MEASURED BY THE S3-2 MAGNETOMETER ON 25 FEBRUARY 1976. The solid line indicates the perturbation pattern.

The comparison of the radar and satellite measurements of both electric field and current are shown in Figure 21. The two sets are generally consistent, assuming that the satellite measurements are displaced by about 1° northward in latitude because of the local-time separation of the measurements discussed above. As shown in Figure 21, the downward current equatorward boundary is exactly coincident with the abrupt increase in E_F .

C. Interpretation of the Measurements

The comparison of satellite and radar measurements during Revolutions 1031 and 1144 indicates a general consistency between the two sets of observations. The ionization, electric-field, and electric-current measurements agree well, provided allowance is made for temporal and spatial variations.

The principal features of the ionospheric electrical properties during the two satellite passes are summarized in Figure 22 and 23. These figures represent a synthesis of the relationships deduced from the radar and satellite measurements. The main features of interest are:

- (1) Latitudinal variations in E-region ionization and conductivity are similar in both passes. However, the latitudinal distribution of F-region ionization differs significantly during the two passes. Latitudinal motions occur in the F-region at S3-2 altitude (200 to 300 km) that are not obviously related to temporal changes in E-region morphology.
- (2) The electric field was directed northeastward in both cases. During Revolution 1031, the electric field penetrated far equatorward of the diffuse aurora and had little variation at the diffuse aurora boundary. In contrast, during Revolution 1144, the electric field was negligibly small in the trough, but was enhanced at the equatorward diffuse auroral boundary and reduced to the north.
- (3) The equatorward edge of the downward (Region 2) field-aligned current was located near the equatorward diffuse auroral boundary. The latitudinal distribution of field-aligned current was consistent

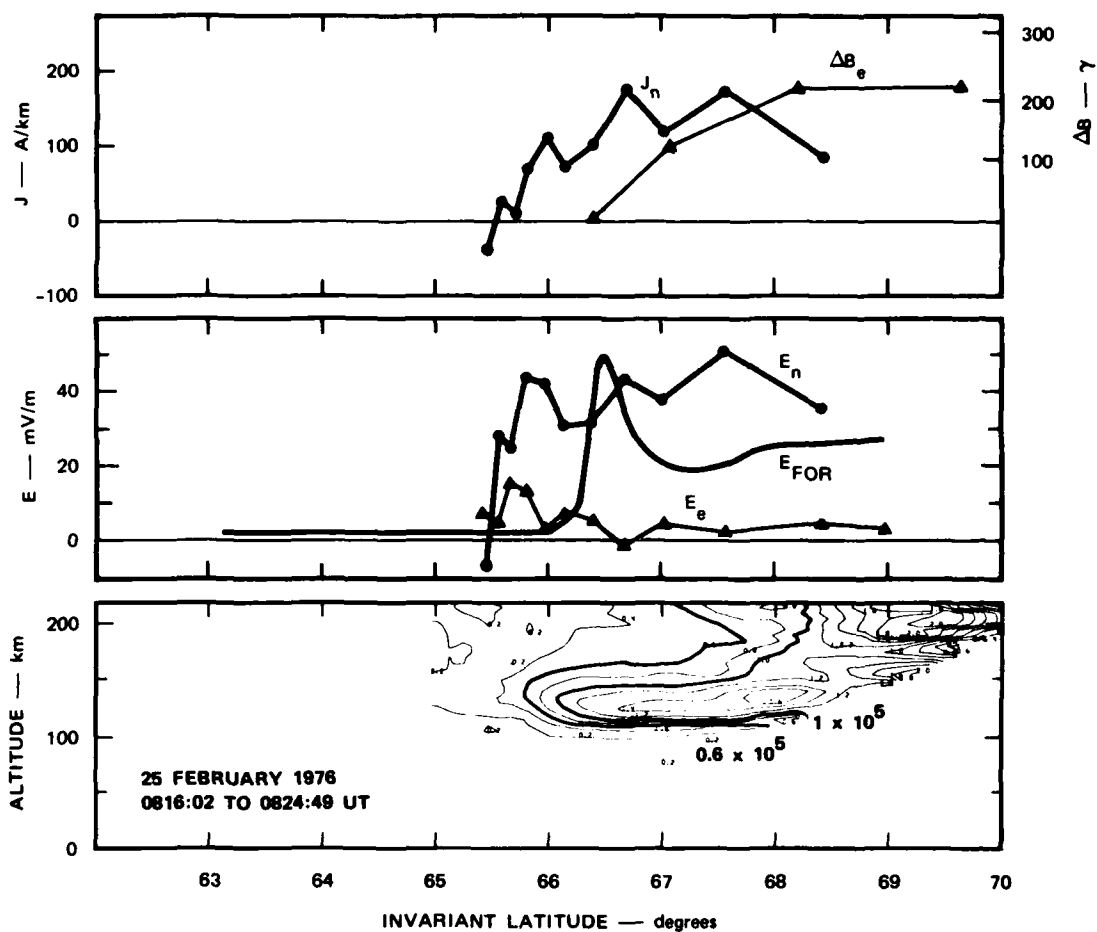


FIGURE 21 COMPARISON OF THE RADAR AND SATELLITE MEASUREMENTS OF ELECTRIC FIELD, NORTHWARD CURRENT, AND EASTWARD MAGNETIC FIELD PERTURBATION ON 25 FEBRUARY 1976

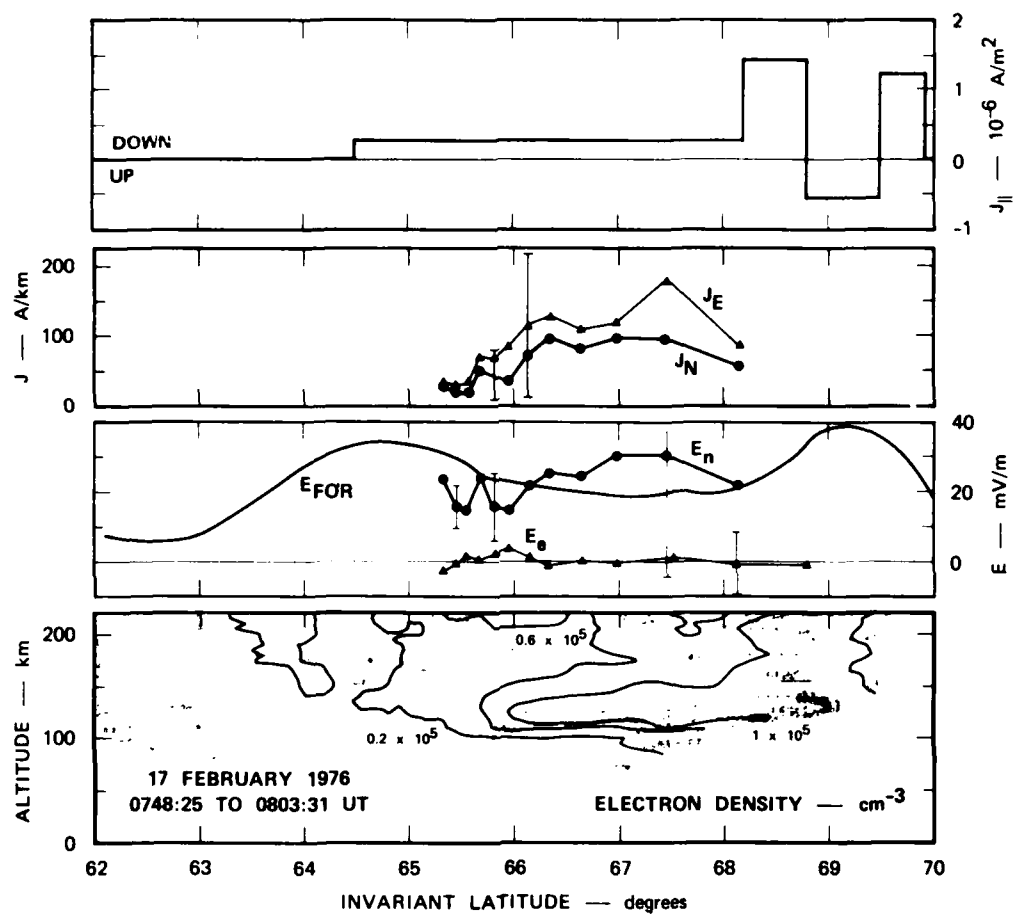


FIGURE 22 SUMMARY OF THE LATITUDINAL VARIATION OF IONOSPHERIC ELECTRICAL PROPERTIES MEASURED DURING REVOLUTION 1031 ON 17 FEBRUARY 1976

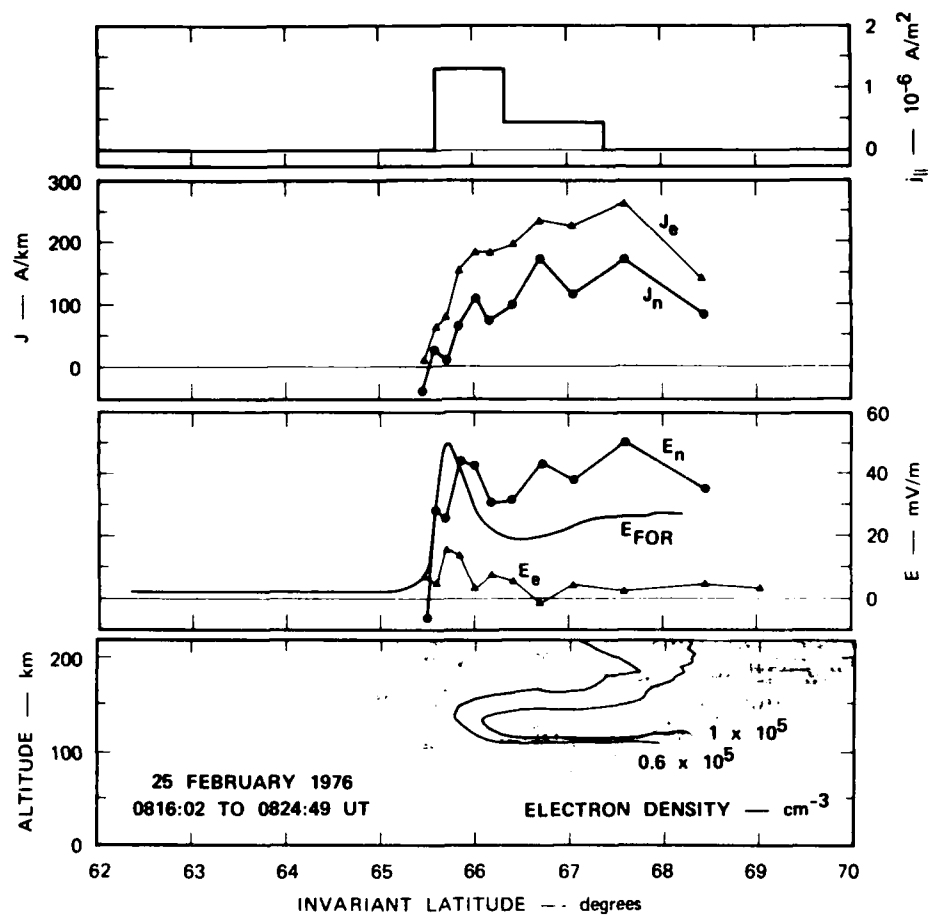


FIGURE 23 SUMMARY OF THE LATITUDINAL VARIATION OF IONOSPHERIC ELECTRICAL PROPERTIES MEASURED DURING REVOLUTION 1144 ON 25 FEBRUARY 1976

with the measured latitudinal variations in the northward auroral electrojet. Because the ionospheric electric field was primarily northward, the horizontal closing current of the field-aligned current system was primarily a Pedersen current, and the eastward electrojet was larger than the northward electrojet.

- (4) During Revolution 1031, the location of the field-aligned current boundaries was not obviously correlated with the latitudinal distribution of the electric field or F-region ionization. However, in Revolution 1144, the downward field-aligned current was generally confined to the region of enhanced electric field. This region of enhanced electric field and downward field-aligned current was located between the equatorial boundary of the diffuse aurora and the equatorial boundary of the enhanced F-region ionization.

The most striking difference between the two passes is the latitudinal distribution of the ionospheric electric field. Although the E-region ionization and conductivity are relatively indistinguishable during the two passes, in one case (Revolution 1144) the electric field terminates abruptly at the diffuse auroral boundary and in the other case (Revolution 1031) the electric field penetrates into the trough. The source of this difference is presumably related to different magnetospheric conditions during these two passes, because the ionospheric conditions are so similar. To verify this presumption, we have examined in detail the geomagnetic activity during these passes as indicators of possible magnetospheric differences.

The magnetograms from College, Alaska during both S3-2 passes were fairly quiet, with only slight positive bays at the time of the satellite passes. Magnetograms for several high-latitude stations (Figure 24) are shown on a common scale in Figure 25 and 26. Both days were fairly quiet, although high-latitude magnetic conditions were somewhat more disturbed on 17 February (Revolution 1031) than on 25 February (Revolution 1144).

AE, K_p , and Dst are global indices of geomagnetic activity that can be used to infer the degree of magnetospheric disturbances. The time

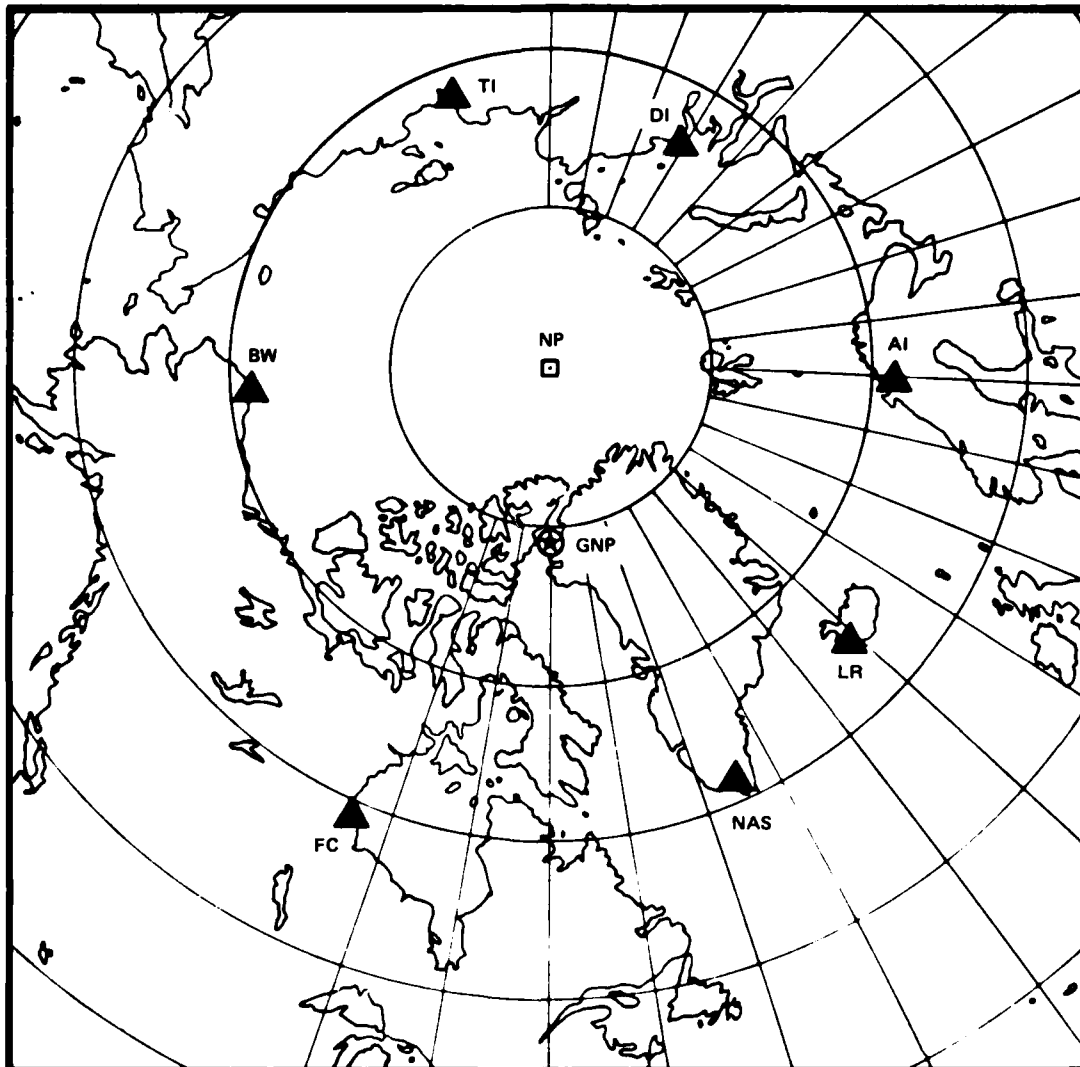


FIGURE 24 LOCATION OF THE SEVEN GEOMAGNETIC OBSERVATORIES USED IN
COMPILING THE AE INDEX

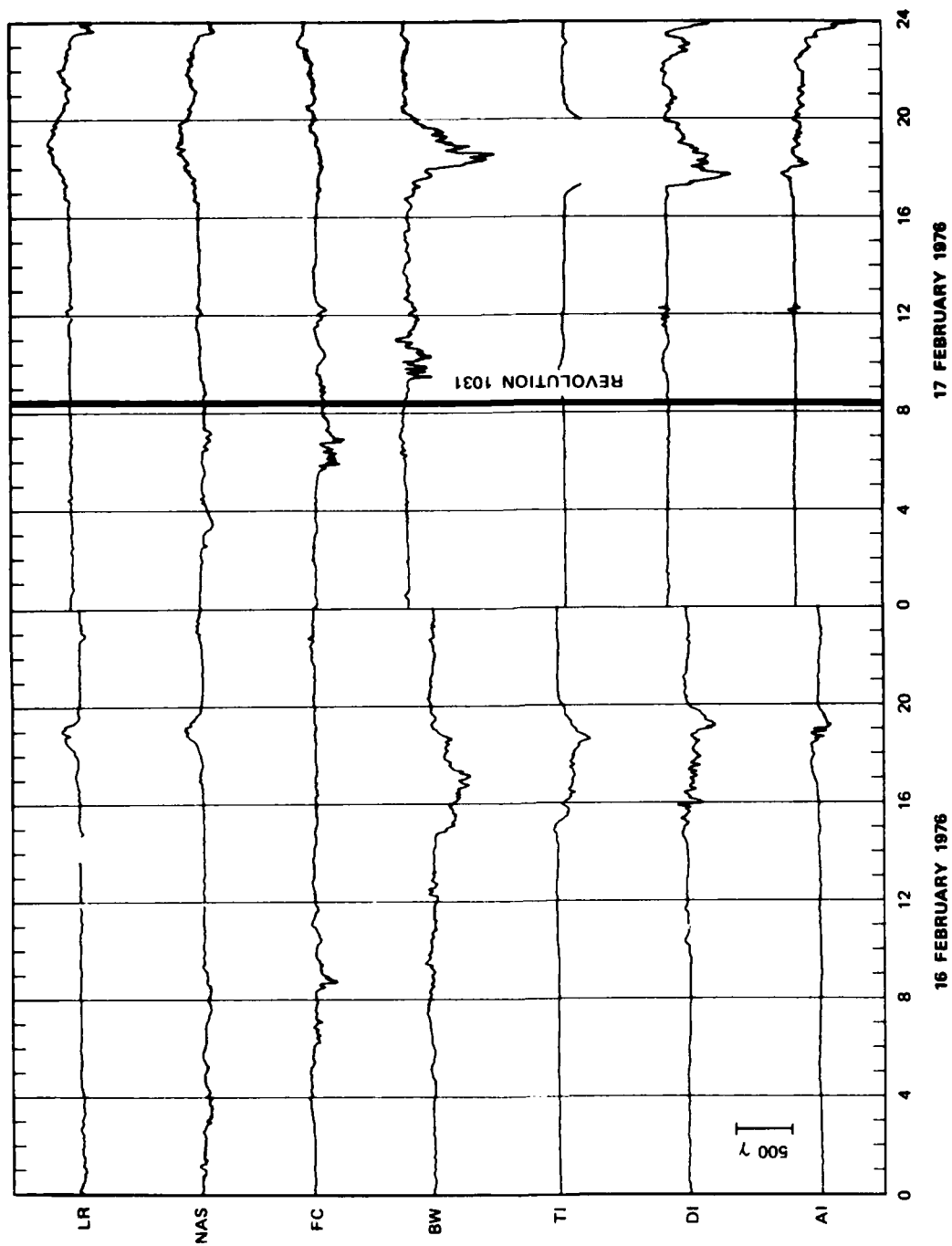


FIGURE 25 COMMON-SCALE MAGNETOGRAMS ON 16 AND 17 FEBRUARY 1976 FOR THE SEVEN LOCATIONS SHOWN IN FIGURE 24

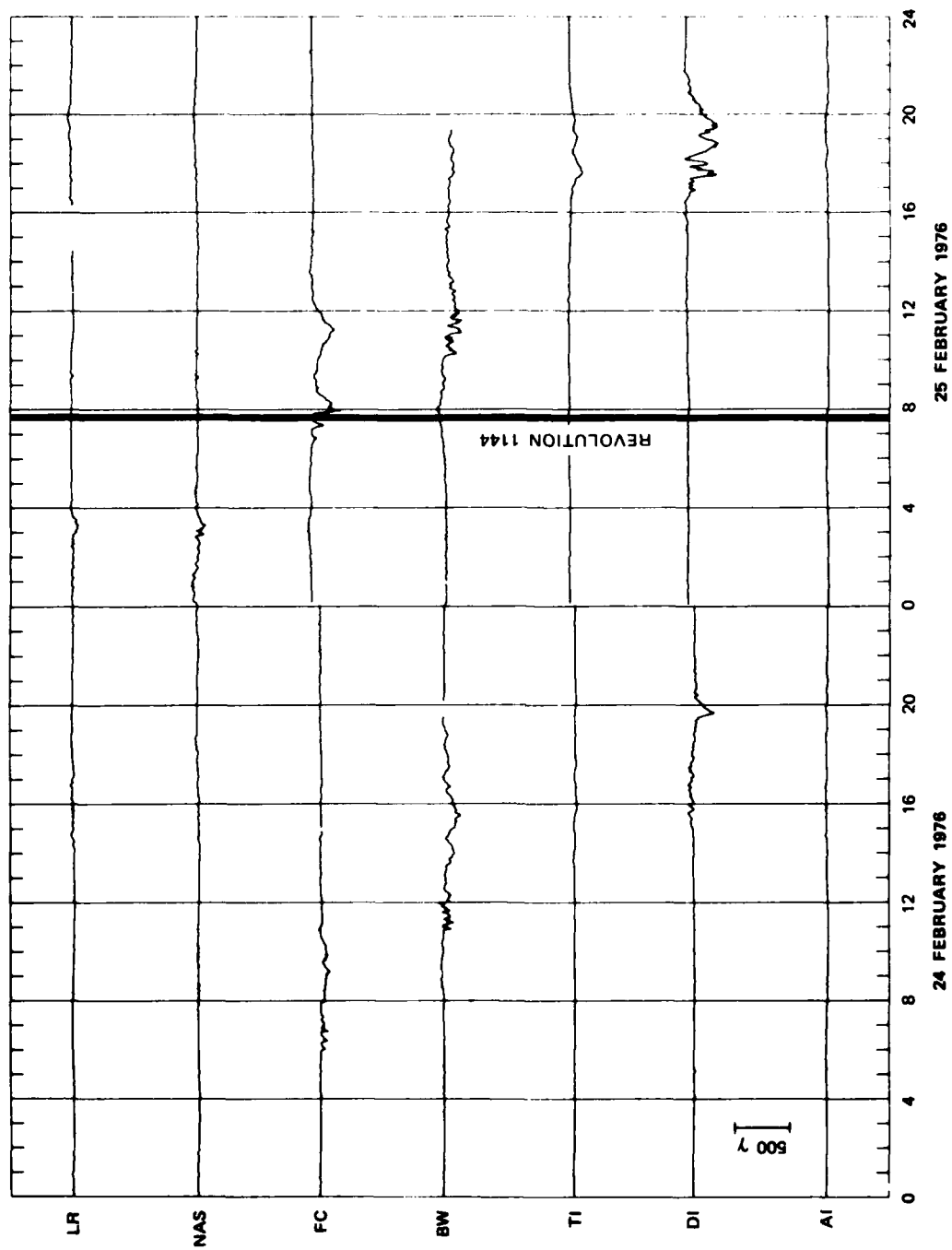


FIGURE 26 COMMON-SCALE MAGNETOGRAMS ON 24 AND 25 FEBRUARY 1976 FOR THE SEVEN LOCATIONS SHOWN IN FIGURE 24

variation in these parameters during February 1976 is shown in Figures 27 and 28 (Allen et al., 1977). Moderate intermittent activity was present on 16 and 17 February, and most of it occurred following a period of southward interplanetary magnetic field, B_z , on the afternoon of 16 February (King, 1979). The pass on 25 February occurred during a period of exceptionally quiet conditions, as indicated by both the K_p and Dst values for the previous 24 hours.

In summary, both passes occurred during periods of relatively low high-latitude (magnetic) activity. The only major difference between the two passes is that Revolution 1144 occurred during a long period of exceptionally quiet K_p and Dst, indicating the absence of a substantial ring current or magnetic storm activity. A period of several hours is required for the development of an Alfvén layer that can shield the penetration of the magnetospheric-convection electric field from the auroral zone to lower latitudes. The abrupt termination of the ionospheric electric field and field-aligned current at the equatorward diffuse auroral boundary during Revolution 1144 may result from the development of strong shielding in a period of prolonged quiet conditions. The unsettled conditions during the 24 hours prior to Revolution 1030 may explain the penetration of the ionospheric electric field to lower latitudes during that pass.

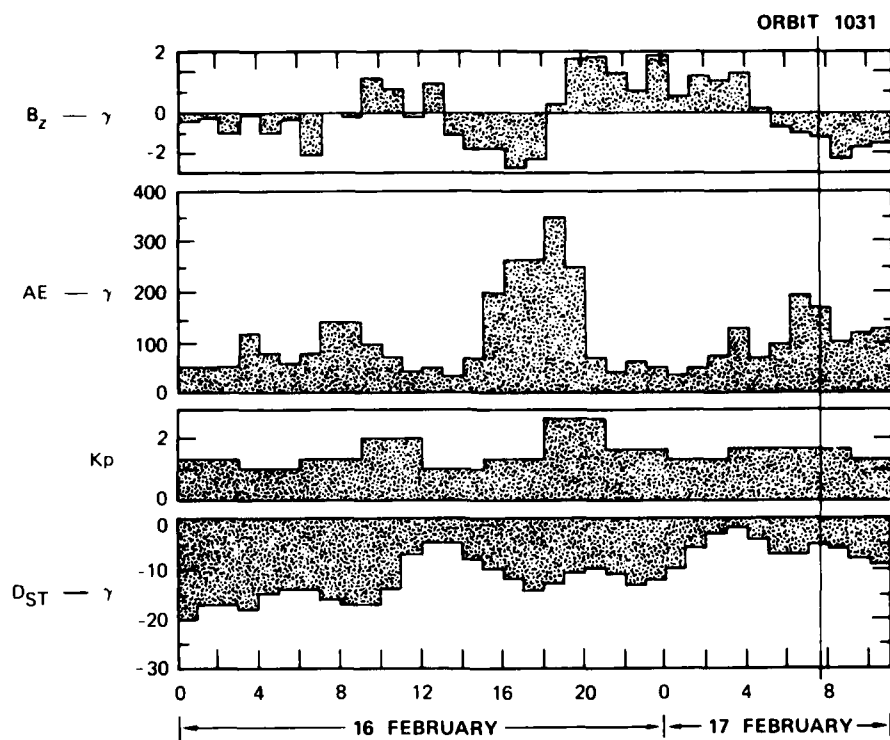


FIGURE 27 VARIATION OF THE INTERPLANETARY MAGNETIC FIELD (B_z) AND THREE GEOMAGNETIC INDICES (AE , K_p , D_{ST}) ON 16 AND 17 FEBRUARY 1976

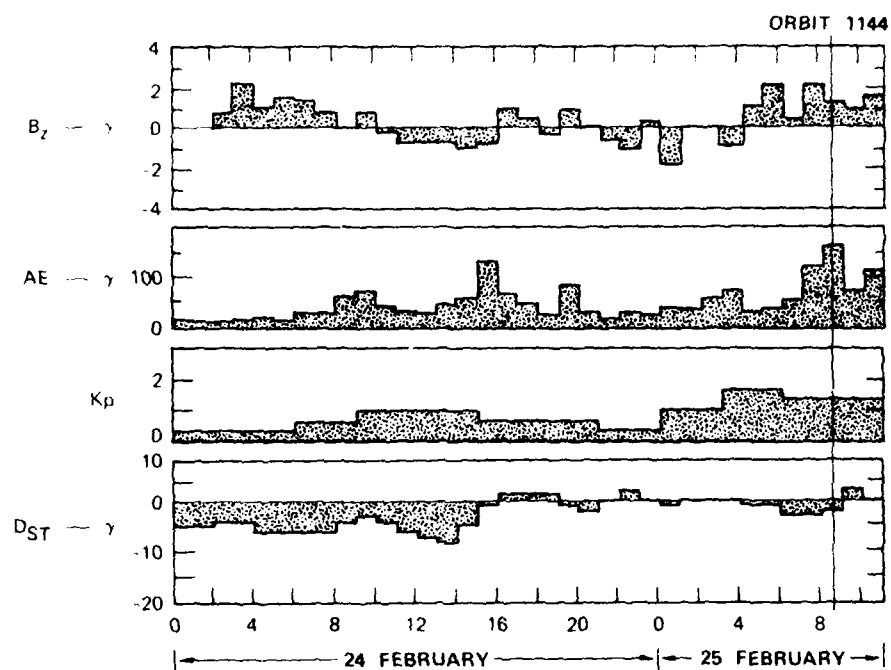


FIGURE 28 VARIATION OF THE INTERPLANETARY MAGNETIC FIELD (B_z) AND THREE GEOMAGNETIC INDICES (AE , K_p , D_{st}) ON 24 AND 25 FEBRUARY 1976

III COORDINATED EXPERIMENTS DURING 1978

The two S3-2 passes described in the previous section were the only useful passes found in the Chatanika/S3-2 data sets from 1976-1977. From January to March, 1978 Chatanika operations were coordinated with intensive S3-2 operations prior to the satellite reentry. As a result of the joint efforts of SRI and AFGL scientists, a large data set of simultaneous measurements was obtained. Since that time, much effort has been made to identify the best coordinated passes from January to March, 1978. Those passes are listed in Table 2, along with a qualitative designation of the scientific interest of the data. Also indicated in Table 2 are auroral conditions and other satellites passing over Alaska near the time of the S3-2 overpass.

Most of the Chatanika data for the passes, listed in Table 2, have been analyzed. Reduced Chatanika radar measurements of ionization, conductivity, electric fields, and currents for all of the high and medium priority passes have been sent to AFGL.

The S3-2 data from the passes listed in Table 2 were not processed at AFGL until after the completion of technical effort on this contract. For that reason, it was not possible to make a comparative analysis of those data and the Chatanika radar measurements.

To illustrate the diversity of auroral phenomena present in the 1978 data, we show two examples of radar measurements. The first example is from Revolution 11478 on 6 February 1978. As shown in Figure 29, a pair of auroral arcs is present just north of Chatanika (65.2° to 66°). The northernmost arc is more intense, with an E-region maximum density of about $3 \times 10^5 \text{ cm}^{-3}$. The diffuse aurora extends from about 63.6° to 65° latitude. North of the intense arc is an absence of E-region ionization. The electric field measurements during this scan showed that the diffuse aurora was associated with a generally northward electric field of about 20 mV/m and an eastward electrojet. The electric

Table 2

S3-2/CHATANIKA COORDINATIONS DURING 1978

Priority	Date (1978)	Time (UT)	Orbit	Auroral Conditions	Other Satellites* (Time, UT)
medium	25 Jan	1032	11296	Diffuse aurora overhead	WB (1000)
medium	31 Jan	1000	11387	Dim arc in south, post-substorm	WB (1029)
high	3 Feb	1020	11432	Bright arc in north	WB (1044)
medium	4 Feb	1000	11447	Arcs in north	WB (0939)
high	5 Feb	2020	11469	Overhead arc	WB (2039)
high	6 Feb	1045	11478	Double arc	WB (1058)
high	7 Feb	1020	11494	Trough (hard precipitation)	WB (0954); TRIAD (1003)
low	8 Feb	1000	11509	Diffuse aurora	WB (1034)
high	9 Feb	0930	11524	Bright arc in north	WB (0929); TRIAD (1042)
high	10 Feb	1035	11540	Multiple arcs; pillar	WB (1008); TRIAD (1017)
low	11 Feb	1010	11555	Dim arc	
high	1 Mar	1016	11830	Pulsating aurora	WB (1031)
high	1 Mar	2059	11837	Daytime, active	WB (2051)
high	2 Mar	1113	11846	Active aurora	WB (1111)
high	3 Mar	1209	11862B	Pulsating aurora	WB (1151); AE-C (1311)
low	4 Mar	1132	11877B	Very quiet	AE-C (1218)
medium	5 Mar	1054	11892	Bright arcs	WB (1126)
high	6 Mar	1148	11908	Dynamic aurora	AE-C (1150)
medium	9 Mar	1122	11954B	Bright aurora	AE-C (1132 ?)

* WB = Wideband; AE-C = Atmosphere Explorer C

field was reduced within the auroral arc. The temporal variation of ionospheric electrical conductivity during a four-hour period around the S3-2 overpass is shown in Figure 30. The equatorward edge of the diffuse aurora is evident about 25 to 50 km south of Chatanika. The bright arc is discernable as the narrow region of enhanced conductivity approximately 100 km north of Chatanika.

The second example is from Revolution 11494 on 7 February 1978. In contrast to all other data shown in this report, the diffuse aurora was not present in the radar field of view. As shown in Figure 31 the only E-region ionization conspicuous during the elevation scan is a narrow patch overhead at Chatanika. The maximum E-region electron density is about $4 \times 10^4 \text{ cm}^{-3}$ at an altitude of 95 km. This is less intense than in the diffuse aurora, but more importantly, it occurs about 25 km lower in altitude. Our preliminary interpretation is that this is an example of a detached arc equatorward of the diffuse aurora. Such phenomena have been identified previously in ISIS satellite images (Moshupi et al., 1979; Wallis et al., 1979) and are thought produced by energetic electron precipitation from drifting plasma remnants of prior substorm injections. The electric field and currents associated with such detached arcs have not yet been measured.

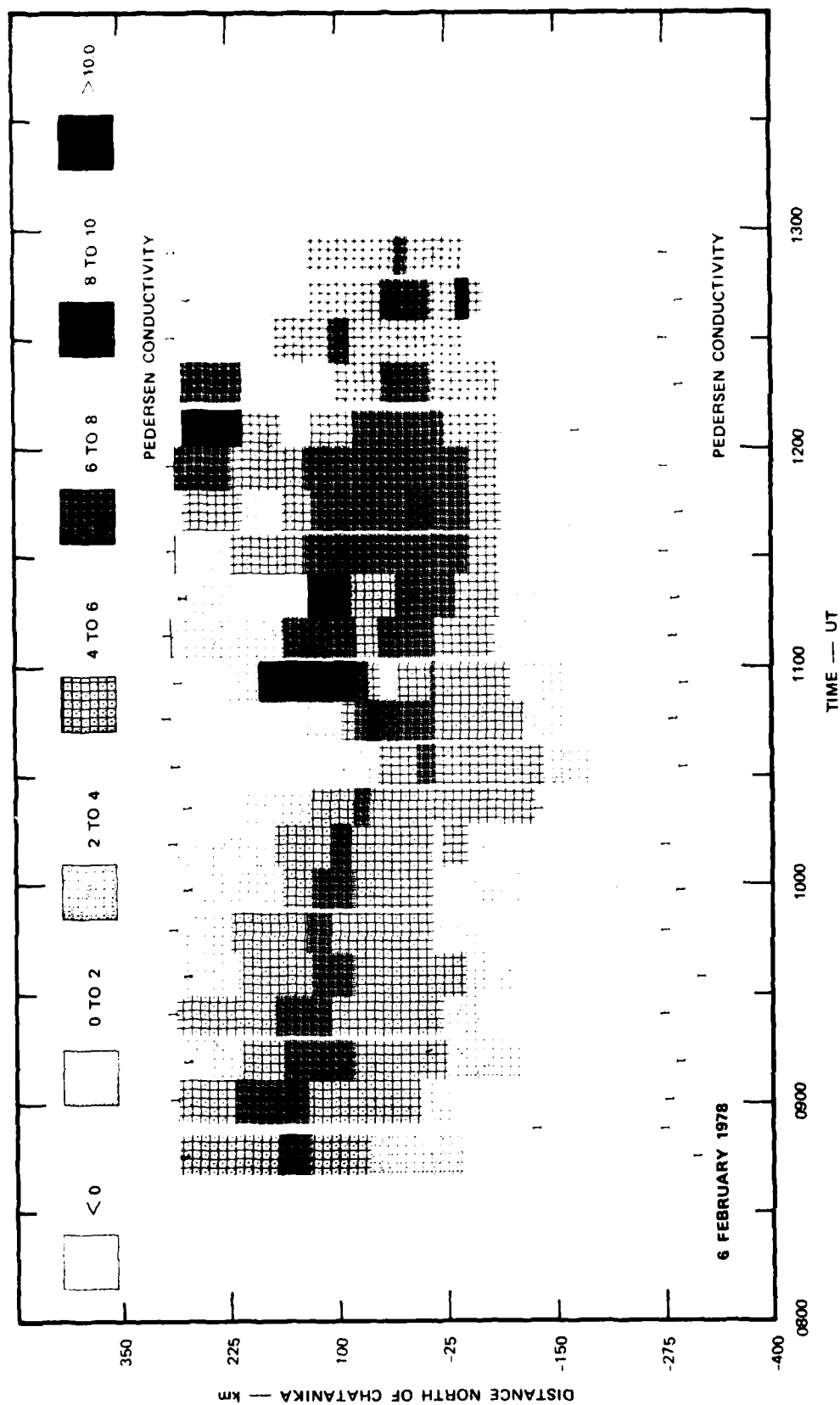


FIGURE 30 LATITUDINAL VARIATION OF HEIGHT-INTEGRATED PEDERSEN CONDUCTIVITY MEASURED DURING 22 ELEVATION SCANS BETWEEN 0840 AND 1300 UT ON 6 FEBRUARY 1978

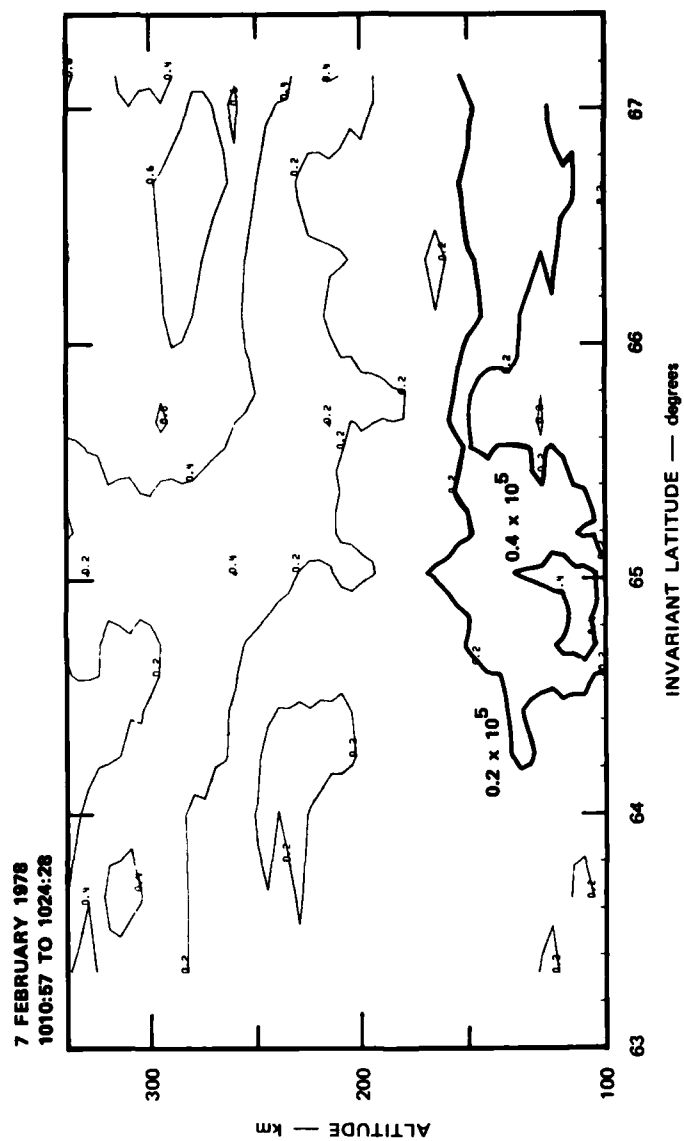


FIGURE 31 SPATIAL VARIATION OF IONIZATION MEASURED DURING THE ELEVATION SCAN BETWEEN 1010:57 AND 1024:28 UT ON 7 FEBRUARY 1978

IV CONCLUDING REMARKS

In this report, we have compared simultaneous measurements of ionospheric electrical properties by the Chatanika radar and the S3-2 satellite. The general consistency between the two data sets shows that such coordinated radar/satellite measurements can be used to infer the distribution of ionization, conductivity, electric fields, and electric currents in the high-latitude ionosphere. Although only two passes from 1976 were available for this study, ionospheric conditions during the passes differed sufficiently so that identification of the magnetospheric influence on the high-latitude electric-field configuration was possible.

The data in this report show the spatial variation of ionospheric electrodynamics in the diffuse aurora. When the S3-2 spacecraft data from 1978 become available, interpretation of the ionospheric phenomena during a wide variety of auroral conditions will be possible by combining the radar and satellite measurements.

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